This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

ELECTRIC LIGHT

ITS PRODUCTION AND USE

BY THE SAME AUTHOR.

Crown 8vo, price 5s. cloth.

ELECTRIC LIGHT FITTING: A Handbook for Working Electrical Engineers, embodying Practical Notes on Installation Management.

"A really capital book. We recommend it to working electricians and engineers."—*Mechanical World.*

"For working electricians it will fill a void hitherto unfilled. It is a good book."—*Iron.*

"A better book on the subject could not be imagined."—*Colliery Guardian.*

Crown 8vo, Second Edition, revised with additions, price 5s. cloth.

ELECTRO-PLATING: A Practical Handbook, including the practice of Electro-typing.

"An excellent practical manual."—*Engineering.*

"Carefully thought out."—*Engineer.*

"Any amateur will find no difficulty in understanding the book from beginning to end."—*Spectator.*

Crown 8vo, price 5s. cloth.

ELECTRO-TYPING: A Practical Manual on the Reproduction and Multiplication of Printing Surfaces and Works of Art by the Electro-deposition of Metals.

"A guide, not only to beginners in the art, but to those who still practise the old and imperfect methods of electro-typing."—*Iron.*

"The book throughout is entirely practical, and is lucid and clear in style. It is a reliable work."—*Paper and Printing Trades Journal.*

CROSBY LOCKWOOD & SON, 7, STATIONERS' HALL COURT, E.C.

ELECTRIC LIGHT

ITS PRODUCTION AND USE

EMBODYING

PLAIN DIRECTIONS FOR THE TREATMENT OF
DYNAMO-ELECTRIC MACHINES, BATTERIES,
ACCUMULATORS, AND ELECTRIC LAMPS

By JOHN W. URQUHART, Electrician
AUTHOR OF "ELECTRIC LIGHT FITTING," "ELECTRO-PLATING," ETC.

WITH NUMEROUS ILLUSTRATIONS

Fourth Edition, carefully revised, with large additions

Capio Lumen

LONDON
CROSBY LOCKWOOD AND SON
7, STATIONERS' HALL COURT, LUDGATE HILL
1891

PREFACE

TO THE THIRD EDITION.

In writing this work, which was first published in 1880, and has since (in the first and second editions) met with a continuous sale, my aim was to give a general view of the means employed at that time in the production and application of the electric light, and no attempt was made to deal exhaustively with the subject. Although the work has necessarily been in great part re-written for the present edition (and thereby enlarged by at least one-third) my aim has still been to preserve, as far as possible, the essentially simple character of the descriptive portions rather than to offer an exhaustive treatise.

In view of the rapid and multiplied developments of the art of electric lighting, numerous additions have been made to the present edition of the work, much of the original text having been removed and its place filled by new matter. On the other hand, care has been taken to retain accounts of the earlier developments of electric machines, accumulators, and lamps which appeared in the previous editions, so that the interesting successive steps which have led up to the systems now in use may be studied by the reader in conjunction with recent discoveries.

The art of electric lighting has advanced so rapidly, that not only have results been attained of which the earlier electricians could scarcely have dreamed, but even the expectations of the later experts have been surpassed. These developments have taken effect in the production of electricity, in systems of distribution, and in the electric lamp.

Accordingly, as might have been expected, an almost infinite variety of electric machines and appliances of all kinds have of late appeared. It was, therefore, obviously impossible to give descriptions of every kind of electric lighting appliance within the limits of the present work. But care has been taken to select for treatment prominent examples of machines, accumulators, transformers, carrying systems, and lamps embodying the chief points of interest or practical value. No apology need therefore be offered for the non-appearance of particular machines and lamps in the book.

I have to acknowledge my indebtedness to several leading electricians, and to many prominent firms, for their kind assistance during the work of revision for this edition.

November, 1889.

NOTE TO THE FOURTH EDITION.

THE third edition having been sold out in a few months, opportunity has been taken, in again reprinting the work, to make a few corrections in the text, and to add two new chapters with illustrations—namely, "Notes on Ship Lighting," and "Electric Light Wiring Tests." In Chapter II. three additional illustrations have also been inserted, making a total addition to the present edition of twelve new illustrations.

October, 1890.

CONTENTS.

CHAPTER I.

INTRODUCTION.

CHAPTER II.

PRIMARY AND SECONDARY BATTERIES.

CHAPTER III.

THERMO-ELECTRIC BATTERIES.

CHAPTER IV.

MAGNETO-ELECTRIC GENERATORS.

CHAPTER V.

ELECTRO-MAGNETO ELECTRIC MACHINES.

CHAPTER VI.

DYNAMO-ELECTRIC MACHINES.

CHAPTER VII.

GENERAL OBSERVATIONS ON MACHINES.

CHAPTER VIII.

TRANSFORMERS AND ELECTRICITY METERS.

CHAPTER IX.

ARC AND INCANDESCENT LAMPS.

CHAPTER X.

ELECTRICAL DISTRIBUTION AND CIRCUITS.

CHAPTER XI.

MEASUREMENT OF THE ARC LIGHT.

PAGE

CHAPTER XII.

MATHEMATICAL NOTES.

CHAPTER XIII.

PRESENT APPLICATION AND COST OF THE ELECTRIC LIGHT.

CHAPTER XIV.

NOTES ON SHIP LIGHTING.

CHAPTER XV.

ELECTRIC LIGHT WIRING TESTS.

LIST OF ILLUSTRATIONS.

ELECTRIC LIGHT.

CHAPTER I.

INTRODUCTION.

IF the extremities of two wires forming the poles of a powerful source of electricity are brought into contact and again gradually separated, the electric current continues to flow across the narrow separation, accompanied by an intense evolution of light and heat. The distance to which the electric poles may be separated without interrupting the continuity of the circuit depends upon the electromotive force of the source and the total resistance of the circuit; it is seldom more than one-fourth of an inch. The air between the two poles becomes heated, and this is the primary cause of the conduction of the current across the break.

The brilliant belt of light thus produced has been termed the *voltaic arc.* If the two poles consist of charcoal or graphite, the luminosity of the arc is greatly increased. The light in this case is supposed by some to be partly due actually to combustion of the carbon, particles of which fly off from one point to the other. On the other hand, it has been pointed out that the incandescence is still more intense in a vacuum, or in any of the gases that do not support combustion, than in the ordinary atmosphere, so that the phenomenon is not to be considered as one of simple combustion. A brilliant light can also be obtained by passing powerful currents through metals of low conducting power, such as platinum, or through thin pieces or filaments of carbon. In all cases of the production of the voltaic arc or electric incandescence, it will be found that a great resistance to the current in a small space has to be overcome by the source of electricity.

The date of the earliest production of the electric light is somewhat uncertain, but in 1810 Sir Humphry Davy, with a battery of 2,000 zinc-copper elements, exhibited at the Royal Institution the electric light with an arc three inches long between carbon points.

The following is the account given in the *Philosophical Magazine*, vol. xxxv., for Jan. to June, 1810, p. 463:—

"In the concluding lecture at the Royal Institution, the large voltaic apparatus, consisting of 2,000 double plates of four inches square, was put into action for the first time. The effect of this combination, the largest that has ever been constructed, was, as might be expected, of a very brilliant kind.

"The spark, the light of which was so intense as to resemble that of the sun, struck through some lines of air, and produced a discharge through heated air of nearly three inches in length and of a dazzling splendour. Several bodies which had not been fused before were fused by this flame; the new metals discovered by Mr. Tennant, iridium, and the alloy of iridium and osmium, zircon, and alumine, were likewise fused; charcoal was made to evaporate, and plumbago appeared to fuse *in vacuo;* charcoal was ignited to intense whiteness by it in oxymuriatic acid gas, and volatilised in it, but without effecting its decomposition."

With regard to this, Professor Daniell, whose elegant and careful writing is still worth quoting at the present day, remarks: *—"The disruptive discharge of the voltaic battery through air is dependent upon precisely the same principles as that of the Leyden battery; but the phenomena are modified by the lower intensity, greater quantity, and perpetual renewal of the force. When passing between two charcoal points, its duration renders it the most splendid source of light which is under the command of art. When the poles of a powerful battery are gradually separated after contact, the discharge takes place through an interval which increases with the heating of the air by the ignited charcoal. With the original battery of the Royal Institution of 2,000 plates, the discharge passed through four inches of air; and with the constant battery of 70 cells the flame is much more voluminous, and extends to the distance of one inch.

"It would, however, appear that the air is not the only form of matter which is concerned in the phenomena, but that particles of the solid electrodes contribute to the general effect by convection. It is probable that the superior brilliancy of the phenomena with charcoal may be owing to the larger number of its solid particles which its small cohesion

---

* "Chemical Philosophy," p. 460.

enables it to throw off in the process. The colour of the light varies with the substances between which the discharge passes. Gold leaf gives white tinged with blue; silver, a beautiful emerald green; copper, bluish white light with red sparks; lead, a purple; zinc, white fringed with red.

"The arc takes place with great brilliancy under the surface of distilled water; some electrolytic effect will at the same time occur, but the greater part of the charge will pass in a brilliant stream of light."

For many years the light only remained a little more than a scientific toy, being occasionally used for lecture purposes, or for the illumination of the microscope; but the discovery of the means of producing electricity in large quantities from mechanical motion through the intervention of magnetism, instead of by chemical action, gave this branch of electric science a new starting-point, and at the present day electric lights on a large scale are entirely produced by currents generated by the rapid movement of insulated wires through a magnetic field. In all arrangements for the production of the electric light we require first a source or generator of electricity; secondly, conducting wires; and thirdly, an arrangement of carbons or metals, at which the light is actually emitted, called the lamp. We shall commence, therefore, by descriptions of the generators employed; and as electricity from voltaic batteries was first employed for the electric light, it will be more in accordance with the history of the subject to commence by describing this means of producing electricity for the benefit of experimenters, notwithstanding that the production of the light by the currents produced by what may be termed electromechanical means is, at the present day, by far of the greater importance.

The following brief note on the units of the electromotive force, the current, &c., may be useful to the student, but it must not be regarded as fully elucidating this branch of the subject.

PRACTICAL ELECTRICAL UNITS OF MEASUREMENT.

Certain units of "Pressure" (correctly termed Potential), of "Flow" (otherwise Current) and of the Resistance to Flow offered by conductors have been adopted. The derivation of these and their physical magnitude may be ascertained by consulting any standard text-book of Electricity. Practical electrical measuring is carried on according to the terms of these units.

The Volt.—The electrical potential difference between the poles of a voltaic battery or a dynamo machine in motion is readily ascertained by means of an instrument termed a *voltmeter*, which indicates the electrical strain, "pressure," or tendency to set up a current, without permitting a current to flow. The instrument shows it in *volts*. For example, the electrical "pressure" shown by one cell of the Grove's battery described on page 26, when little or no current is passing is very nearly 2 *volts* (1·95 volts). An Edison dynamo machine (p. 157) would indicate 110 *volts*. Electric pressure is very generally and correctly termed *Electro-motive force*, abbreviated E. M. F. or E.

The Ampère.—This unit refers to the *current* or flow of electricity. As the magnitude of the current depends greatly upon the Resistance of the conductor through which the current flows, the two units are generally considered together. Thus, the current that would flow in the circuit of the Grove's cell of two volts if its total resistance were 1 unit (1 ohm) would be approximately 2 *ampères*, abbreviated C.

The Ohm.—This refers to the *resistance* to flow presented by a conductor. The legal ohm is the resistance presented by a column of pure mercury, 106 centimeters in length and 1 millimeter in section. Resistances of conductors are ascertained by comparison (balancing) with standard ohms by means of an instrument well known as a Wheatstone's Bridge and a delicate galvanometer. Resistance is abbreviated R.

The Watt.—If the electromotive force (in volts) between the poles of a dynamo be multiplied by the current (in ampères) the result will be the external or useful electrical activity in watts. 746 watts are called an electrical horse-power. An incandescent lamp is said to need 4 watts per candle-power, or 60 watts in all to "run" it. Thus, about 12 lamps are said to call for an electrical horse-power. The watt is usually abbreviated P (power).

Several other units are used, but not generally, as the Dyne (force), the Joule (work), Coulomb (quantity), Farad (capacity), Gauss (magnetic field). Compare also equational numbers, p. 356.

CHAPTER II.

PRIMARY AND SECONDARY BATTERIES.

As a source of electricity for permanent electric lighting the voltaic battery is in our opinion practically useless. Some recent developments of batteries for house-lighting, spoken of at p. 35, may, however, be regarded by some as a satisfactory refutation of this statement. It is frequently required, to produce small voltaic arc lights for the illumination of the optical lantern, the microscope, and other instruments of that description. Although the voltaic battery is somewhat costly in working, and is generally considered a troublesome source of electricity, it may in some cases be made extremely useful for experimental and lecture purposes, and even for temporary lighting of interiors. Very few laboratories and lecture-rooms are as yet supplied with dynamo-electric machines or other sources of powerful currents. It is probable, therefore, that for some years to come the voltaic battery will be used in many of the minor applications of the electric light. In such instances it may be considered a handy and even inexpensive source of electricity.

The theory of the voltaic battery and the laws appertaining to the voltaic circuit are not treated of in these pages. The many excellent text-books of electricity adequately supply this want. A very slight acquaintance with electricity will enable the novice to use a voltaic battery. Unless the young experimenter adopts certain precautions, however, it is not unlikely that he may find this source of current both costly and troublesome. On the other hand, an acquaintance with the working of the battery may enable him to employ it without inconvenience. As a source of small currents for experimental and testing purposes, he will find a voltaic cell almost indispensable.

Voltaic batteries of a type suited to the production of the electric light are few in number. The batteries that are generally employed in working telegraphs or ringing house-bells, or even in electro-plating, are all too weak for our purpose.

We require a battery of small size to supply for a short period a very energetic current of electricity. We also must have a generator that will not vary much in power during about two hours. It should be inexpensive at first, and in working its cost must be low, while it should not give any trouble during the time the light is required. It must not waste its materials, but give all the benefit derived from the consumption of zinc as current.

All batteries consist of one or more cells, in which are placed two substances, the one more oxidisable than the other, and acted on by acids more or less diluted. The most oxidisable substance is termed the positive element, and the other the negative element Electricity of opposite name is believed to flow off in contrary directions in equal quantities from the surface of generation—viz., the junction of the liquid with the positive plate; but for convenience, the current is supposed to flow from the positive element through the liquid to the negative element, thence from the terminal on the negative element through the external circuit of wire, earth, or other conductor back to the terminal of the positive element. *The current is supposed, therefore, to leave the battery at the terminal attached to the negative element*, and this terminal, or the end of any wire attached to it, is termed the *positive pole*.

In the same way the *terminal or wire attached to the positive element is termed the negative pole.*

Construction of Batteries.

Positive Elements.—In nearly all batteries the oxidisable metal, or positive plate or element, is zinc, and the current is therefore produced by the slow consumption or combustion of zinc.

PRACTICAL DIRECTIONS.

The best zinc for this purpose is that known as rolled Belgian. Its cost is about fourpence per lb. The plates or cylinders should be about $\frac{3}{16}$ths of an inch in thickness, and in electric light batteries must be amalgamated; that is, coated with a closely adherent film of mercury. Zinc, when new from the rolling mill, is greasy, and this film should be dissolved off in a hot solution of caustic soda. To cut zinc plates to size is a more difficult matter than is generally supposed. The simplest way is to make a deep scratch at the place of separation, repeat this on the opposite side, and run mercury into the cut. This will soak nearly through in a few minutes, and the plate may be divided by bending over the edge of a table. To bend zinc plates into cylinders it is only necessary to heat them in hot water and curve them over a wooden cylinder.

A question now arises as to whether the zinc plate is to be provided with a *binding-screw*, or is it to have a copper strap soldered to it? Binding-screws are procurable of all kinds. Some are made for soldering to zinc plates, and others for screwing upon them.

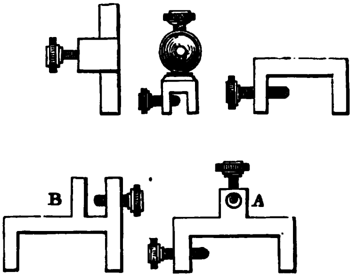


Fig. 1.—Binding-screws and Clamps.

Fig. 1 represents some specimens of binding-screws, of which the smallest, with rounded head, is best suited for screwing upon plates and cylinders of zinc. For soldering, the same screw is made with and without plain stems. Conducting straps of copper should be cut from sheet, and of uniform width, with a length of 5 inches. They are usually attached to zinc cylinders for use in Bunsen's cell. It is by far best to drill a hole in the zinc and strap, and to securely rivet the latter to the cylinder. The joint should be quite firm, the copper where it touches must be *clean*, and a coating of Japan or other varnish will protect the connection from corrosion.

When a connection is to be soldered, a tinman's "iron" should be used, although the blow-pipe is frequently employed for this purpose. The flux generally consists of a weak solution of chloride of zinc. The solder itself is a mixture of tin and lead, generally known as "soft solder." In connections between copper wires, or copper and brass, it is advisable to use resin as a flux. Joints made in copper cables with the aid of zinc chloride have been known to become "rotten."

To amalgamate zinc, dip the plate for a minute in acidulated water, one to ten; pour the mercury into a shallow vessel, and, while the zinc surface is wet, distribute the mercury upon it with a pad of cotton or tow until a perfect surface is secured, and the mercury covers the plate. If there are parts where the mercury will not "take," dip the plate again into the dilute acid and repeat the process; finally, set the plate up on edge to drain off the superfluous mercury.

If the plate is not amalgamated, "local action" will reduce the current in strength and waste a great deal of the zinc. The mercury connects the various impurities of the zinc together, and prevents the local action from commencing. After use, if the plates show black patches, they should be re-amalgamated.

Negative Plates.—Receiving or negative plates in electric-light batteries are usually of the dense variety of carbon known as graphite, found in gas retorts after gas-making. It may be scaled off. Its price at the gas-works is trifling, as it is, otherwise than for batteries, of little use. The best carbon, which aids the development of the current, is very hard, of a grey colour, and dense crystalline structure. It is, therefore, very difficult to cut, and unless proper appliances be at hand, in the shape of a revolving disc of iron, fed with silver-sand and water, it will be found cheaper to buy the plates and blocks from the instrument-dealers.

The Excitant is, as a rule, sulphuric acid diluted with much water.

Containing Cells.—The containing cells have a capacity from half a pint to a gallon. Quart size is very well suited for electric-light batteries. The single-liquid cells have only one containing vessel, while those that are double have two. Outer cells may be of glass, but, as a rule, glazed earthenware is stronger and more suitable. When a considerable number of the cells is required, it will be found that the makers can supply them at a much cheaper rate than the instrument-dealers.

Porous Cells are of unglazed earthenware. They are made usually in two shapes—round tubes, long and narrow, and in oblong form, for use in Grove's battery. They are placed within the zinc cylinder, or U-shaped plate, and usually contain the negative element.

Such cells, to be suitable for electric-light purposes, must not be hard and dense, while the thickness of the sides should in no case be over $\frac{3}{16}$ths of an inch. The softest are of red-ware; but better cells, and sufficiently porous, are made from white clay. A test of the porosity should be taken by placing water in the cells, and allowing them to stand for some time. If, after about 15 minutes, a dew does not appear on the outside of the cell, it is probably too hard or thick, and will offer too great a resistance to the current. If, on the other hand, the water actually runs off the side, the cell is *too* porous, and will shorten the period of the action of the battery by too rapid transfusion of the liquids into each other. This mixing action is correctly called *endosmose*, although the term is also applied to the peculiar creeping of solutions of metallic salts, such as the copper sulphate used in Daniell's cell. Porous cells are easily procurable of instrument-dealers.

Composition of a Cell.—A voltaic cell must be composed of two dissimilar metals or materials immersed either in one or two liquids. The one-liquid cells, although convenient enough for short experiments, so rapidly acquire a film of gas upon their negative plates that the development of the current is speedily impeded, hence such cells, unless the excitant be agitated in some way, are unfitted for supplying current for any length of time.

In the two-liquid cells the negative plate is surrounded by a liquid rich in oxygen ; hence the hydrogen, which is, in single-liquid cells, set free at the negative plate, is, in such a double-fluid cell as Grove's, absorbed by the oxygen of the nitric acid. In the more effective two-fluid batteries the negative plate is by these means kept quite free from a film of hydrogen. This fault in single-fluid cells is generally known as polarization. It will be of interest to observe that what here is a fault is really the fundamental principle of the various electric accumulators, secondary or storage batteries lately introduced.

Two-liquid cells are, however, more troublesome, and may be set aside in favour of single-liquid ones for many short experiments.

Bichromate Cells.

Besides the series arrangement of coupling up the cells, which is shown in Fig. 2 and diagramatically by Fig. 3, the elements may join up in parallel as shown by Fig. 4 ; or again, we may have a combination of the series and parallel arrangement as shown by Fig. 5, which represents 12 cells joined up, four in series and three in parallel. The electro-motive force of a combination of cells as shown by Fig. 5 is that due to the number of cells in *series*—*e.g.* is equal to four cells. The joining up of the cells in parallel does not alter the electromotive force, it merely diminishes the resistance in proportion to the number which are in parallel. Thus the resistance of the whole combination is one-third of the resistance which four cells alone in series would have, since we have three in the parallel number. The most advantageous combination to be adopted in particular cases depends upon circumstances, but the object aimed at is to make the internal resistance of the combination equal to the external resistance through which the current has to flow—this makes the latter the greatest possible.

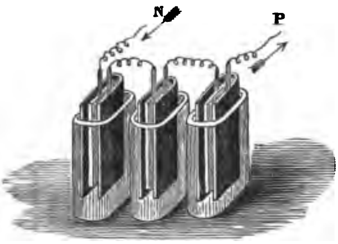


Fig. 2.—Simple Voltaic Cells.

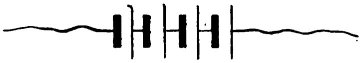


Fig. 3.

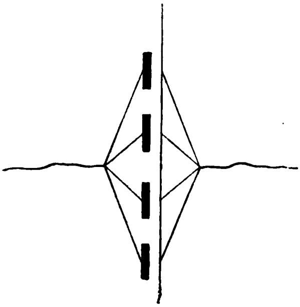


Fig. 4.

Two wires, it will be seen, convey the current from a coupled-up battery of cells, and scarcely any action commences within the battery until the ends of these conductors are brought together in metallic contact, or until some circuit, such as that of one composed of wires and an electric lamp, is provided for the electricity to flow from and back to the battery.

For electric-arc light purposes it is generally best, up to 50 cells, to join up *in series* (Fig. 3)—zinc, carbon, zinc, carbon.

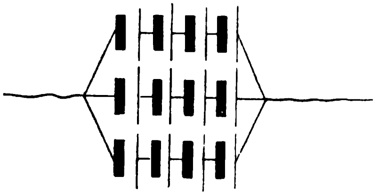


Fig. 5.

A plate of zinc between two plates of carbon then forms a single element of the battery. A brass clamp may bind the whole together, the zinc being prevented from contact with the carbon by strips of wood as thin as possible, while the two carbons are connected as one by the brass clamp. Elements, or sets thus made up, can be charged with dilute sulphuric acid if a fairly strong current only is required; but for electric-light purposes, requiring a powerful and steady current, the containing vessel should be three-fourths filled with a mixture as follows:

Crystals of bichromate of potash	3 oz
Water	1 pint.
And (when cool) sulphuric acid	2 oz.

When this liquid is fresh, it causes the pairs immersed in it to give off a great deal of èlectricity—that is, a strong current.

PRACTICAL DIRECTIONS.

Pairs of bichromate of potash cell plates should not be immersed in the solution until the current is really required and all is ready. Of course, all the pairs, joined up by spirals of wire, may lie near the cells until the time comes for placing them in the liquid; but a much better device, and a most convenient and cheap containing cell, is exhibited in Fig. 6. Bottles of this shape, and to contain about a quart, are easily procurable. The neck should be sufficiently large to admit the pairs of plates, while the liquid is not readily splashed over the top. Attached to one of the cells is shown a stout brass collar, A, soldered around the neck tightly. To this is securely attached an upright stout brass wire, bent as shown at B. The object is, of course, to provide a convenient hook upon which to suspend the pairs of plates when removed from the liquid. All the cells should have this arrangement, and may be put out of action in a moment by pulling up and hooking the plates by their wire or in a loop soldered on the clamp.

Fig. 7 exhibits a more expensive and elaborate form of the bichromate of potash cell known as the "Grenet" pattern. It is very handy for experiments, and requires little attention. The pair of carbon plates extend downwards from the wooden or ebonite cover of the bottle to the bottom, and remain permanently in the liquid. The carbon is not injured by this continuous immersion. The liquid will *keep* for a considerable length of time, but the time it will *work* is, of course, limited to perhaps 15 minutes, if the bulk be small. The zinc plate is attached to a sliding rod, movable in a split brass tube fastened to the cover, and may thus be lifted clear of the liquid, so as to throw the cell out of action. This prevents waste of the zinc and the solution.

The carbon plates are made fast by screwing or riveting to stout angular pieces of copper, and these being connected together, and having soldered to them the stem of a binding-post, one wire serves as before for both plates. The split tube is connected by a strip of copper or brass to the other binding-screw. The ebonite cover—or a wooden cover will do equally well—is furnished with a brass collar to fit over the neck of the bottle.

Fig. 6.—Battery Cells.

Fig. 7.—Small Bichromate Cell.

Fig. 8 exhibits another shape of bottle, of larger size, as usually employed in the construction of cells of great capacity. The zinc should be as large as possible, and its top should be furnished with a piece of ebonite cut to fit between the carbon plates, to prevent the zinc from twisting and closing the circuit within the cell.

The art of working bichromate cells consists, first, in never leaving or placing the zinc in the solution when the current is not required, removing it the instant the experiment is performed, and in not leaving it in the liquid for over five minutes without either disturbing the liquid or moving the plate. The great defect of such cells is the want of circulation in the liquid, so that, when the latter is allowed to remain quite still, the current is soon weakened. If heat can be applied, so as to cause some circulation, the current will come off almost in full even flow until the solution is exhausted. Exhausted solutions may be thrown away, or they may be allowed to spontaneously evaporate, when the chrome alum formed in the action may be recovered. This salt is of value in dyeing.

Fig. 8.—Bichromate Cells.

PRACTICAL DIRECTIONS.

All the connecting wires should be insulated, and at least as thick as No. 16 Birmingham wire gauge. All connections must be clean and metallic; electricity will not pass through dirt, coatings of oxide, or cotton covering. Connecting points in clamps should be occasionally examined, to prevent imperfect contact. Bad connections will weaken the current, and sometimes stop it altogether. To give some convenient elasticity, the connecting wires may be wound on a rod to form a spiral; but too much wire must not in this way be introduced into the circuit, as the current may be weakened by its resistance. All connections to lamp or instruments should be thick, or No. 12 copper wire. All uninsulated wires must, of course, be kept from contact together, otherwise the circuit may be closed outside the battery before it reaches the electric lamp or other instrument.

Fig. 9 represents a form of bichromate battery in much favour, as it admits of a great number of plates being placed in and withdrawn from the liquid at one movement. The arrangement also permits of the easy agitation of the liquid. The author has seen a battery of this kind of 25 quart cells give a beautiful electric light for a considerable time by an ingenious arrangement of a weight, wheel, and lever rocked by a crank applied to the lifting-gear. In this way the plates were raised a little way, and then dropped every second, thus agitating the liquid—the result being a steady current.

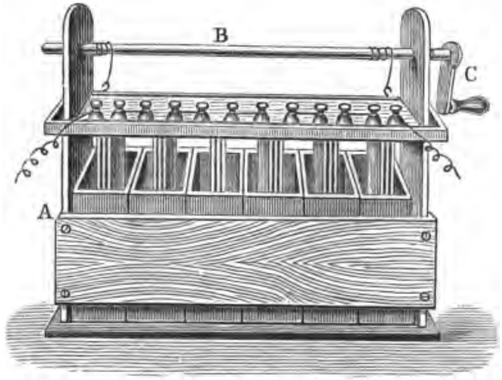


Fig. 9.—Six-cell Lifting Battery.

A is a wooden frame, accommodating as many oblong glazed cells as may be required. The plates are all attached to a wooden holder above them as exhibited, above which are attached the binding-posts as in other forms of the cell. This holder is capable of sliding vertically upon A, by means of the handle and spindle with cords, B and C.

Number of Bichromate Cells required.—This depends upon the amount of light required. A light will be given by 6 cells of quart size, but it will be a small light, and will not permit of any actual separation of the carbon points; 12 cells will yield much more than double the light, and 24 will admit of actual separation, giving the true voltaic arc and a very brilliant light; 50 cells will give rise to a voltaic arc of great splendour, probably equal to 1,500 candles.

It may be said that, up to 50 cells of the quart size, it is generally advantageous to connect up in series for use with ordinary electric lamps.

The electromotive force of 50 cells is usually sufficient, and any greater number of cells should be connected in parallel circuit to an equal consecutive number of cells of the 50 elements, so as to reduce the internal resistance of the battery whilst maintaining a sufficient electromotive force. Thus, if there are 100 cells, each 50 should be joined up in series, and then the negative wires from both should lead to one screw of the lamp, and both positives to the other screw. Thus the electromotive force of the battery is not increased, but the resistance of the elements that are doubled is halved. But as before stated, the most advantageous mode of grouping a given number of elements must depend on the resistance of the external part of the circuit; for with a given number of elements they should be so grouped that their internal resistance shall equal the external resistance. It will be unwise to expect over half-an-hour's continuous light from any bichromate of potash battery; and there must be agitation of the liquid to get even this amount of light. The solution may be refreshed afterwards by the addition of 2 ozs. of sulphuric acid to the pint.

Constant Batteries.

Bunsen's Cell.—The original battery invented by Bunsen consisted of a cylinder of carbon for the negative element; and the zinc, in the form of a cylinder also, was placed within the porous cell. This form is expensive to make, and also more expensive in use than that now known as the Bunsen cell.

Fig. 10 is a view of a Bunsen cell of approved construction. The outer vessel is of glass. The positive

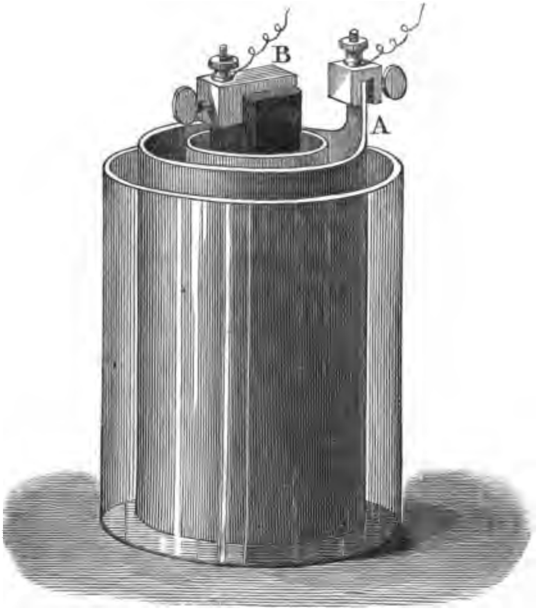


Fig. 10.—Bunsen Cell.

element consists of a cylinder of thick sheet zinc, to fit loosely into the outer vessel. A is a projection left upon the zinc in the process of cutting it to size; it serves to provide a fastening for the binding-screw clear of the liquid. The screws are of brass. Within the zinc cylinder is a vessel of porous earthenware, as before indicated, and in this porous vessel, completing the cell, is placed a cylindrical or square block of gas carbon, with a binding clamp, B, fastened to it.

The roll of zinc, A, should not be a *complete* cylinder. The edges should not come quite together; a division, however narrow, should be left while bending. Both inside and outside of the cylinder should, and indeed must, be amalgamated, as is done with flat plates, and care is necessary to renew the amalgamation as soon as black patches are observed to form upon the surface.

As to the actual making up of Bunsen generators, as here exhibited, the outer cells should contain nearly a quart of liquid at least. They are best made of brown well-glazed earthenware, as before recommended. The zinc cylinders should be cut to the size in the flat sheet, leaving the stem for the screw upon them for connection, and then bent over a wooden former while hot. The porous pots should be higher than the zinc, and the zinc should be higher than the outer cell. A soft porous cell is the most suitable, of white or red materials. Within the porous cell is placed the carbon block, which should be highest of all, and may be either round or square; but square blocks are almost always used, and are easily procurable at about ¾d. per inch in height, retail. A hard, clear, grey carbon should be chosen, and black and porous varieties rejected, because they add to the resistance of the circuit and reduce the force otherwise.

PRACTICAL DIRECTIONS.

It is a common practice simply to clamp the carbon by a binding-clamp of brass for the connection. This is, however, when the cell is to be used much, a bad and decidedly troublesome way of getting contact. It is by far better to give the block a heading of lead. To do this, dry the head, cut a notch or two around it ¼ inch from the end. Melt the lead and pour it into some square mould, such as a cavity made in hard putty or plaster of Paris. Before the lead sets, dip in the carbon end, and allow the whole to solidify before removal. While still hot the binding-screw may be soldered on, and before it cools the whole should receive a coating of melted pitch; or, which is much better, dip the head in melted (solid) paraffin, which, when cool, will effectually defend the connection from outside attacks of the acid.

A better way still, although not so quickly accomplished, is to electrotype a heading of copper upon the rods, to insure the best possible connection. To do this, partly fill a porous pot with acidulated water; place this in an outer cell containing crystals of copper sulphate dissolved in warm water. Heat the rods, and give them a coating of paraffin, driven in with a hot iron, between where the liquid will reach up to and where the heading will reach down to. If any paraffin spreads upon the end, drive it back by heating; cut now a few notches in the head as before, and drill a hole right through, in which place tightly a piece of stout cotton wire, having ¼ inch of the end projecting at each side. Tie a wire around the carbon block, at the end of which fasten a strip of zinc, which place in the porous cell, while the carbon head dips into the copper solution. As soon as this is done, a deposit of copper will begin to form upon the wire and carbon, and when it has attained a thickness of good brown paper, remove the block, drill two holes right through the copper and carbon, soak a little time in warm water, dry off, and place for some time in melted paraffin to obtain an efficient protection. The binding-screw may be soldered to the copper, which will be found of the greatest utility as a heading which cannot be attacked by the acid.

The exciting liquids are:—

In the outer cell with the zinc . .	1 part sulphuric acid; water, 4.
In the porous cell, with the carbon .	strong nitric acid only.

This "charge" will work the cell for about 4 hours. After this the outer acid will have exhausted itself; but the nitric acid, which will have turned from a clear liquid to a reddish colour, may be used again. The second time of using will turn it green, and the third time quite clear again, when it should be thrown away and replaced by fresh. It is no economy to use nitric acid of inferior quality; it should be concentrated.

The Bunsen, while at work, gives off the fumes of the nitric acid, which renders it necessary that the battery should be placed out of doors, or in a place where there is a draught of air. These fumes are poisonous; they are worst while the porous cells are being emptied into the nitric acid stock bottle, but may be quite avoided in the open air.

PRACTICAL DIRECTIONS.

In the working of large batteries of the Bunsen cell, some special arrangements are required to enable the attendant to get through the work of charging quickly and accurately. First, the sulphuric acid mixture must be prepared in a large bottle beforehand, by pouring the acid into the water—*not the reverse*—and stirring. It is most convenient to have a graduated measure, by means of which the correct quantity of nitric acid may be determined before placing in the cell. This is of more importance than might at first seem to be necessary; but a measure that can be quickly and easily filled to a known point, and as speedily emptied into the cells, will not only be cleanly, but will prevent spilling the nitric acid into the zinc compartment, an accident which sets up violent local action upon the zinc. It will first be necessary to find how much liquid will fill the porous pots to within one inch of the top when the carbons are placed in them, and then to fill all the cells with the carbons and zincs near at hand. It is further of consequence to have the liquid within the porous cell at the same height as that in the outer pot.

The battery should not be put in action until within a short time of its being required. A dish of water should be at hand in the case of accident by burning the hands with nitric acid, and it is well for the attendant to have in use his oldest clothes, because nitric acid will, if dropped upon them, destroy the part. Quickly place the zincs and carbons in their respective cells first, and then go backwards over the series, making the connections with certainty. See that each screw is well home, and that there is no bad connection throughout. As to the time such operations occupy, a battery of 50 Bunsens may be unpacked, put into action, and the light produced within twenty minutes.

When the porous cell of the Bunsen battery is charged with a strong solution of the bichromate of potash, as recommended for the single-liquid cell, its force is very little diminished and the fumes of the nitric acid entirely avoided. Of late, most experimenters have abandoned the use of nitric acid in favour of the chromic acid.

PRACTICAL DIRECTIONS.

Again, in pulling the battery to pieces after operations, all the connections should first be loosened; then the zincs should be placed one by one in a bucket of water to wash off the acid. The carbons are next similarly treated, and after putting a funnel in the neck of the nitric acid bottle, the porous pots should be emptied one by one, and then plunged in water. The outer liquid may be thrown away, as it is useless, or nearly so. Porous pots should, after once being used, be kept in water for a few hours to soak out any nitric acid or zinc sulphate, which, while dry, would crack them. All connections should be well washed and dried, and before again using should be looked to for oxidised or bad contact points, which must be scraped bright or filed.

Zinc cylinders showing black patches should be again amalgamated, but this will probably be unnecessary until after the third time of using.

The force of the Bunsen will increase after setting up for about an hour, and the full effect will not be attained until the acid soaks through the porous pot. Carbons, as in bichromate batteries, are not affected in the least, and will last any length of time. The zinc is consumed slowly, through the mercury coating.

Twenty-five cells of the Bunsen will give a very brilliant light, and 50 will produce an arc of great power, while 100 will, when coupled in two parallel circuits of 50 each, so as to give an electromotive force of 50 volts and a resistance of a few ohms only, produce effects of the most splendid character. The conducting wires must be thick—about No. 12, and even stouter conductors should be employed when 100 cells are used, joined up in parallel circuits of 50 each.

Fig. 11 is a view of a pair of Bunsen cells of a superior finish, for laboratory use. They are fitted with removable screws upon both the carbons and zincs. The containing vessels are of glass. The engraving exhibits the separation which should be made between the edges of the zinc cylinder. This separation is chiefly for the purpose of preventing the formation of local currents in the zinc, while it also assists the outer liquid to more freely circulate.

Various arrangements of the Bunsen cells may be adopted in making up a handy battery. The framework and lifting arrangement spoken of in connection with the bichromate cell is also applicable to the Bunsen. There is, however, one disadvantage in the two-liquid cells, and it consists in the diffusive tendency of the two liquids, whether the cells are in action or not. It is thus almost impracticable to arrange a rackwork frame for the Bunsen, so as to obtain the convenience of the arrangement to the extent previously described in reference to the bichromate. It is better, however, to have the means of lifting the elements out of their cells, as it is useful when the battery is put into action for short experiments extending to about one and a half hours. During this time no great mixture will have taken place, and the zincs and carbons, arranged on the lifting-board just above their respective cells, may be lowered as required. There are some advantages in the frame used in this way. Bunsen batteries are most convenient when put up in long boxes while in action.

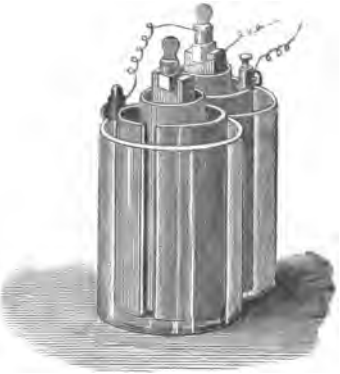


Fig. 11.—Pair of Bunsen Cells, showing connections.

Iron Cells.

With the primary idea of effecting economical working, a cell has been tried, the invention of Mr. Slater and others. All that can be here said of it, as well as of every other form of cell in which iron is employed yet introduced, is that they are entirely unfitted for use in inexperienced hands. The iron cell is objectionable in many ways, but its chief fault would appear to be the tendency of the acid in the iron compartment to boil over when least expected. Such cells are, moreover, false economy, as will be found on working them for electric light, although the first cost may be lower than that of the Bunsen.

Chromate of Lime Cells.

To replace the potash salt with greater economy and equal power in working, a cell of the double-liquid kind has been devised by Messrs. Fitzgerald and Molloy, which is said to be about as constant as the Bunsen, while it is almost as effective in working, and is undoubtedly cheaper when properly made.

The chief point in the construction is to secure as large a negative surface as possible, and, by means of a soft porous cell, to reduce the internal resistance of the combination.

Several forms of make-up have been tried. The best is a cylinder of carbon surrounding a large porous cell containing the zinc as a cylinder. Carbon cylinders are difficult to make. The graphite must be ground finely, or that deposited as powder upon the retorts may be used direct. It must be mixed into a stiff dough with water and sugar syrup, then baked until hard, and, while still hot, plunged in a strong solution of sugar or tar, and finally heated to whiteness and cooled slowly.

Another construction of the cell is arranged as follows:—A large soft porous cell is taken, in which is placed centrally a thin rod of carbon, or a Bunsen rod, with a screw affixed. Around the rod is packed a quantity of broken carbon in lumps as large as hazel-nuts. Over the top is run melted pitch, and a conical hole is left for the introduction of the liquid. The outer vessel, as in the Bunsen, contains a cylinder of zinc, and its diameter should be only just enough to admit the porous cell freely, the object being to have the zinc near to the negative element. In order to allow the outer liquid greater freedom of action, the zinc cylinder should have a separation of about ½ in. The cell is thus a carbon and zinc one, like Bunsen's. The exciting solutions are, however:—

FOR POROUS CELL.

Chromate of lime	2 ounces.
Water	5 ,,
Sulphuric acid	5 ,,

FOR THE OUTER CELL.

Water	1 pint.
Sulphuric acid	3 ounces.

The action will be found to give off little or no fumes. The electromotive force is slightly greater than that of the Bunsen; but the internal resistance is also greater.

This same cell is available for use with another excitant, which will be found to work even with greater force, and give little or no fumes for the first two hours:—

FOR THE POROUS CELL.

Bichromate of potash	2 ounces.
Nitric acid	10 ,,
Sulphuric acid	2 ,,

In the outer cell the solution is the same as for the Bunsen. This will be found to work with greater power than the Bunsen, owing to the arrangement of the carbon, and the internal resistance is less, but the cost of working is rather greater. After use the porous cells should be emptied of their liquid contents, and kept in water until again wanted. The same solution may be used two or three times, and if there be any appearance of a poverty of potash salt, more should be added.

Various modifications of such cells may be used. As a rule it is best to provide a strongly acid mixture for the carbon compartment. Thus the cell above mentioned, as its construction is virtually the same as the Bunsen, may be used with great advantage as a Bunsen, and it will give a greater current than the common forms, while the cost of construction is very little more.

Cells Too Weak.

Avoid attempting to produce the electric light with the following cells :—Daniell, Smee, Manganese, Sulphate of Lead, Sulphate of Mercury, Chloride of Silver, Marie Davy (mercury sulphate cell), Copper-Zinc (simple), Minotto (modification of Daniell), Léclanché, Highton, Clark's Mercury, Peroxide of Iron, Perchloride of Iron, Callaud's, Spiral Cell, Meidinger (modification of Daniell), and, in short, all cells used for telegraphy or bell-ringing.

The Grove Cell.

This cell admits of a very large and powerful battery being placed in a very small compass. Grove's cell is like the Bunsen, except that platinum foil is employed instead of carbon. The solutions are the same—that is, strong nitric acid in the porous pot with the platinum foil, and acidulated water in the zinc cell. To obtain the greatest power, it is most effective when made up in cylindrical vessels like the Bunsen.

Fig. 12 represents the zinc cylinder of a Grove cell.

Another make-up, adapted to the purposes of lecturers and where great portability is necessary, is shown in Fig. 13, where A is the zinc plate, in a flat outer cell, and B the platinum foil plate, in a flat porous vessel.

Fig. 14 exhibits these cells with the elements removed. Porous cells of this kind are more expensive than round ones. They should be thin in the sides, but the ends and bottoms for strength may be thicker with advantage.

Fig. 12.—Zinc Cylinder.

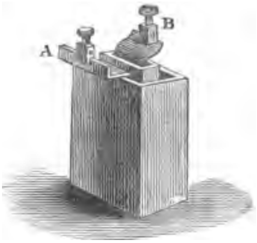


Fig. 13.—Grove's Cell.

Fig. 15 shows how the zinc plate should be bent, so that it may embrace the porous cell closely. The generator has thus a great deal of zinc surface. To increase the otherwise somewhat small surface of the platinum plate, it should be corrugated, or simply very much wrinkled; but it is better to corrugate it in the direction of its length, which will both increase the effective surface and add to its stiffness. Fig. 16 shows the platinum plate arranged for the cylindrical zinc of Fig. 12. A is a cover of wood or ebonite to which the plate is made fast, and a connecting strip leads to the binding-screw holder, B, which is of brass or copper sheet, bent at right angles, and secured to the wooden cover by two screws. It is a mistake to purchase platinum foils too thin. There is no waste, but foil that is like tissue-paper is a source of constant trouble.

Practical Directions.

The chief objection to the use of platinum is its great cost, as it is not procurable as sheet or wire under £1 10s. per oz.; but an ounce of platinum will go a long way in foil of sufficient thickness for use in the Grove cell. The connection may be soldered on, but it is usually better to solder on a clamp-piece of sheet-copper first, across the top edge; and to protect this metal from the fumes of nitric acid, it should be coated, while warm, with Brunswick varnish, or sealing-wax dissolved in warm methylated spirits of wine. Any kind of clamps or screws may be used, but it is most convenient to have them removable.

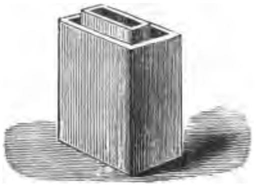


Fig. 14.—Pots for Grove's Cell.

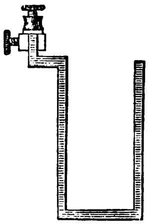


Fig. 15.—Zinc for Grove's Cell.

Fig. 16. Platinum Plate.

Fig. 17 represents a ten-cell Grove's battery, as used by lecturers for the production of small electric lights. It is composed of the flat cells, and the foils are clamped by plain clamps to the succeeding zincs throughout.

The resistance of Grove's battery is very small, and on this account it will give, size for size, a stronger current than the Bunsen when the external resistance is small, although the difference does not warrant the extra expenditure except for travelling purposes, or when space is limited. A Grove's cell will cost about three times as much as a Bunsen. Twenty Grove's cells, or two cases of ten as the one shown, will give a good light, and five such cases of ten, coupled up in series, will produce effects of great grandeur.

It is of greater importance than with most other cells to have the conductors and connections used in Grove's batteries very stout and of good soft copper. The time this battery will remain in action is about the same as that given by the Bunsen. The Grove cells may be smaller than the Bunsen to produce the same effects. The same care is necessary in keeping the zinc amalgamated, and the bottom, or bend, is usually better rounded and should be well watched for worn portions or patches becoming unamalgamated. Less nitric acid than is used in Bunsen's will be sufficient in the Grove cells. The author has used Bunsen cells made up in Grove vessels with complete success for operations extending over 2½ hours. Plates of carbon must, of course, be used instead of blocks, and they should be as thin as may be convenient. This make-up is more expensive than that of the common shape of Bunsen. Grove porous cells should have a lip at one corner for convenience in pouring out the contents.

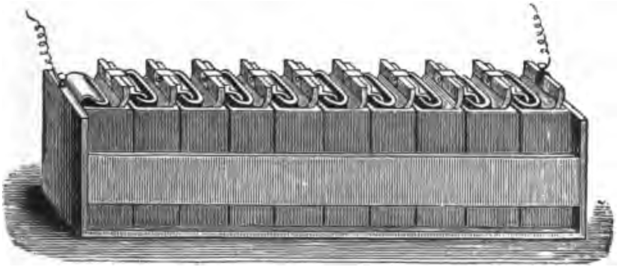


Fig. 17.—Ten-Cell Grove's Battery.

Battery for Photographer's Light.

It has long been known that the electric light is rich in actinic rays, and on this account it is of much value to the photographer in securing views of places and objects not reached by the light of the sun, or in the practice of portraiture.

It may be said that a good electric light will be found to work the rapid dry plates of to-day almost as easily as daylight at noon.

Since the introduction of cheap dynamo-electric machines and gas-engines, photographers in various cities have taken up the new light, and at the present time it is an easy matter, in London, to get a portrait taken at night in more than one place in Regent Street and elsewhere. Not every photographer, however, can afford to go to the necessary outlay of about £110 for a gas-engine and machine with lamp.

The author has devised, in a modification of Dr. Byrne's cells (a battery in which a constant agitation of the liquid is kept up by means of a current of air), a voltaic generator free from most of the objections generally urged against the application of batteries. It is at first inexpensive, is easily managed and certain in results, and its maintenance low enough in cost to warrant its extensive use. It is, further, very portable, and may be made use of in travelling to secure photographs of caves and such places. It is not procurable commercially, and the intending user is therefore recommended to make it for himself, for which purpose full instructions are given, with an illustration of the apparatus.

Assuming that the reader, from glancing at previous pages, is sufficiently acquainted with the usual construction of a voltaic cell to understand readily minor details not here mentioned, it will be best to premise further remarks with an explanation of the nature of this generator. It is, then, a simple bichromate of potash cell, with negative plates of a peculiar construction, and so arranged that a very powerful current may be obtained from even 6 cells by the aid of much agitation of air.

PRACTICAL DIRECTIONS.

Each negative plate consists of a plate of copper, to one surface of which, as well as to its edges, a sheet of platinum foil, compact, and free from pinholes, is soldered, and to the opposite surface or back, a sheet of lead—the three metals being so united that the copper shall be effectually protected from the action of acids. The lead back and edges are then coated with asphaltum varnish, acid-proof cement, or any other like substance; and lastly, the platinum face, being first rubbed over gently with emery cloth, is to be thoroughly platinised.

To Platinise.—Fill a containing vessel and a porous cell with acidulated water, and place the porous cell within the large vessel. Tie a strip of zinc by a clean wire to the plate to be platinised; dip the zinc in the porous cell, and the plate in the outer cell, and drop into the outer cell, while stirring, a solution of platinic chloride in water. Add drop by drop, with agitation, until the platinum surface is seen to turn dark, and to have acquired a granular deposit of platinum. Upon this surface depends to a great degree the power of the generator. If any difficulty is experienced in securing a good deposit, dip only a little of the zinc in the solution at first, and increase as the coating is seen to form. Dry carefully, and do not scratch the plate or remove the deposit, which it is not difficult to do before it is dry.

Each cell contains two such plates, between which a single zinc is suspended, and when the elements are immersed so that the exciting fluid reaches to within an inch of the top, a large negative surface is brought into action.

It will thus be seen that the platinum alone is the negative, or receiving metal, and the copper core a conducting body merely; while the lead, being almost passive, serves no other purpose than to protect the copper, so that any other, and, best of all, a non-metallic substance capable of resisting the action of bichromate solutions, might, with advantage, be substituted for the lead. The exciting solution to use in this cell is prepared as follows :—

Bichromate of potash	2 ounces.
Warm water	1 pint.
And, when cool, sulphuric acid	4 ounces.

Practical Directions.

Fig. 18 represents a six-cell generator of this kind. The cells are the ordinary brown glazed earthenware oblong ones used for the Grove and other batteries. They should be capable of containing at least a pint of the liquid; quart cells will be found more economical. There are three plates in each cell—two platinised plates, and one amalgamated zinc between them. They are separated at their top edges by slips of wood or ebonite, against which they are securely clamped by stout brass clamps as shown. Thus the brass clamp, being in metallic contact with the lead, with clean scraped surface, represents them both as the positive pole. To the zinc plate in the centre is soldered a common binding-screw. Very stout and soft copper wires—about No. 12—must be used to connect up the elements in series, zinc to platinum, zinc to platinum, and so on, with clean contacts. The sets of plates are fastened to a framing of wood, made to slide up and down the side uprights by means of an overhead shaft, cords, and handle F. This allows of the plates being drawn out of the solution the instant they are out of action to save zinc and solution, as previously described for common bichromate batteries. A ratchet wheel should be put upon the spindle, with adjustable pawl, to hold the plates in position when drawn up. For quart cells the plates may be 8 in. long by 4½ wide.

The air-distributing arrangements of this apparatus are as follow:— A A A is a piece of ½-inch lead piping, fastened to the back of the framework, from which lead, as shown, 6 smaller tubes (¼-inch) of rubber or varnished lead. These extend to the bottom of the cells, and then run parallel with and directly under the plate edges. The ends are closed, and the horizontal portion is perforated with many small holes. B B is a rubber pipe slipped over the end of A, its other end being made secure to the outlet, C, of a hand-pump D, worked by the handle E. The air-pumping arrangement exhibited in the figure is not very effective—one of Mr. Fletcher's foot-blowers has been found much more efficient.

If these elements are lowered into the solution simply, it will be found that a much greater power is obtainable from them than that given by zinc-carbon batteries, previously mentioned. The full effect, however, for which this valuable battery is remarkable, can only be obtained by pumping in air by the small tubes. A great disturbance of the liquid results, and the current is so much augmented in power that even a 6-cell battery will yield a light equal to that given by a 20-cell Bunsen or Grove.

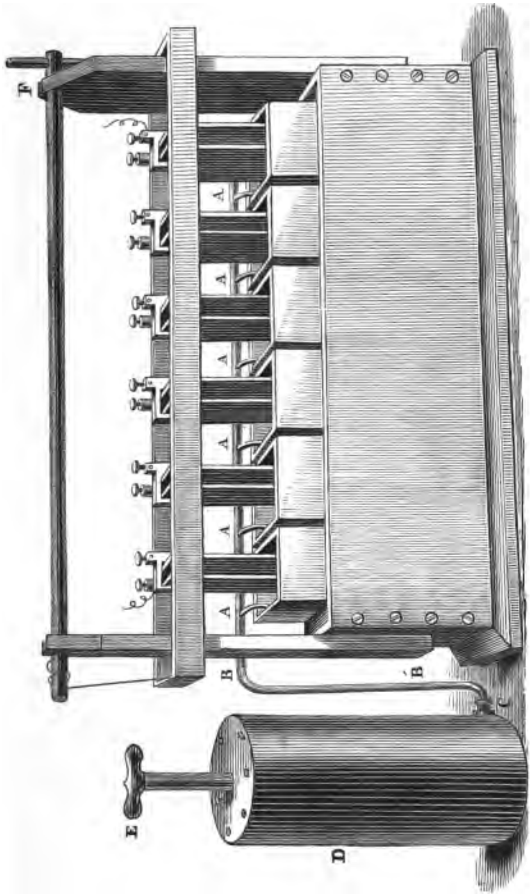


Fig. 18.—Bichromate Pneumatic Battery.

The air disturbance has no effect upon the electromotive force of the battery, although the volume of current given off is enormously increased, and any other means of effecting the required agitation would probably answer the purpose equally well. The suggestion of Professor Adams as to the air effecting a free circulation in the fluid, by which the metallic surfaces are kept constantly clear, is undoubtedly the correct explanation. The wonderful effects are in great part due to the low internal resistance of the cell, owing to the peculiar arrangement of negative plate, partly to the peculiar effect of a rapid flow of air upwards through the liquid, and partly to the production of heat. The action of the air-flow is principally mechanical, but by hastening the combustion of the zinc it tends to generate heat, which in turn reduces the resistance. The mechanical action of the air is to remove from the neighbourhood of the negative plate the chrome alum which is formed there, and from the surfaces of the zinc plate the zinc sulphate, formed by its union with the sulphuric acid; and to bring a fresh supply of solution constantly to the surfaces.

With a battery of 10 cells, a platinum wire, 32 in. long, of No. 14 gauge (·089 in. in diameter), was gradually brought to a glowing red heat, which ebbed and flowed with the cessation or renewal of the air-flow. A brilliant electric light is maintained between two carbon points, which similarly varies in intensity with the flow of air, so that it is important to pump the air in regularly; and when this can be done by a crank attached to a heavy fly-wheel, almost perfect regularity is secured. The effects which are ordinarily produced by 60 or 70 Grove or Bunsen cells were obtained from 10 cells of this battery in the laboratory of Mr. Spottiswoode, F.R.S., at Sevenoaks.

Batteries for House-Lighting.

The primary voltaic battery has for many years been a kind of *ignis fatuus* to inventors. The possibility of being able to generate electricity in sufficient quantity for house-lighting without the aid of a prime motor and a dynamo is a sufficiently attractive pursuit even to electricians. To those who have studied the subject, and have fully grasped the fundamental relations of electro-chemical reactions, however, the great question is susceptible of an easy and conclusive answer. Inventive talent of a high order has been lavished upon the production of improved batteries. All kinds of ingenious devices have been resorted to. But while this is true of the years between 1881 and 1888, it is also true of certain periods between twenty and thirty years ago, so that many of the recent patents for primary generators are but revivals of old ideas. The perfecting of the incandescent lamp, providing, as it does, a suitable burner for house-lighting by electricity, has necessarily given a great impetus to the efforts of inventors of batteries. While twenty years ago the electric lamp was as great a source of trouble as the battery itself, it was manifestly an almost impossible task to permanently light houses in this way, even if we neglect the question of prohibitive cost. Now the lamp difficulty has been removed, and yet the question cannot be said to be satisfactorily solved.

Much has, however, been done. Many installations of electric light fed by batteries are actually in use. But it is a curious fact that in the most successful of these, the primary has had to be wedded to the secondary battery or accumulator (page 40), and the installation consists of a large voltaic battery for supplying the current, and an accumulator battery for storing it. The fact is, that when inventors succeeded in producing the primary generator, its action proved to be, what is true of all voltaic cells for large currents, of a variable nature. The lamps would be alternately too bright or too dull, so that the accumulator, which is an admirable regulator, had to be called into use for this purpose.

Notwithstanding that our conviction is that primary voltaic batteries will never be used generally for electric lighting, it will prove both instructive and interesting to glance briefly at the main features of one or two of the most recent and meritorious of these inventions.

It is both remarkable and regrettable that several inventors of batteries have stooped to a kind of quackery for the purpose of disposing of their wares. We allude to that which all students of science regard with great contempt—the practice of making public all about the battery except the "excitant," the "depolarizer," or the nature of the elements used. In such cases, the "special" mixture with which the battery is to be charged has to be purchased from the inventor, who thus enjoys a monopoly of the sale of the stuff, the nature of which he is generally afraid to entrust to the safe keeping of Her Majesty's Commissioners of Patents. Of such inventions we have nothing further to say.

The Lalande Battery.—This battery (patented 1882) came before the public in 1884. Each cell consists of an iron tray containing, in the form of a layer, the depolarizer, composed of oxide of copper. Placed parallel to and above the layer of copper oxide is the zinc plate, which is supported from each corner of the tray. The cell is then filled with a solution of caustic soda. It is claimed that when the circuit is open, no action takes place between the elements. Upon the circuit being closed, the oxygen of the oxide of copper attacks the zinc, producing an oxide of that metal, and leaving metallic copper in place of the oxide of copper.

The special and interesting feature of the battery (the prior invention of which is claimed by Mr. A. R. Bennett) is no doubt the fact that the zinc oxide, when collected, has a value above that of zinc, and can be used for paint. The inventor claims that this product has a value 56 per cent. above that of zinc. When the battery is exhausted the oxide of copper, or rather the residual product, can be revivified and used again. It is obvious that such a battery presents many points of advantage. Its action is fairly constant and reliable, and it is free from fumes. No doubt its great drawback is its low electro-motive force. In the hands of Mr. Fergusson, who has considerably improved the original battery, and who uses caustic potash in place of caustic soda, the cell has assumed a more practicable form for maintaining glow-lamps. Each cell consists of an iron trough 24 in. long, 12 in. wide, and 18 in. deep, holding fifteen gallons of liquid. The negative surface in this case consists of folded iron gauze, into which is passed an agglomerate of oxide of copper and chloride of calcined magnesia. This is then heated, and forms a hard plate. When the plate is exhausted it is heated in a furnace, which revivifies the oxide constituent. The negative plates thus prepared are 20 in. long, 18 in. deep, and $\frac{3}{8}$ in. thick. Four plates are placed in each cell, presenting a working surface of 1,280 sq. in. The positive plates are of zinc, two in number, 20 in., 15½ in., and ¼ in. thick; active surface, 1,240 sq. in. The excitant is a solution of caustic potash of sp. g. 1·25, and the resulting electromotive force of the cell is slightly under one volt. In the case of the installations of this battery set up in London, the whole is placed in a cellar, from which there is an opening into the street. The company working the invention keep the battery in order. When the solution becomes saturated with zinc it is removed by means of a "vacuum cart," and fresh plates are supplied as required. The spent liquid is treated for the recovery of the zinc. *It is said* that by means of this battery the cost of voltaic electricity has been enormously reduced.

The Upward Battery.—Mr. Upward brought out a battery in 1886 which has some promising features. This inventor conceived the ingenious idea of generating the acid just as it is required in the battery, doing away with a charge of acid, or any powerful excitant in the cells during the time of rest, or when the circuit is open. The cell is of glazed earthenware, divided into porous compartments containing carbon plates packed with crushed carbon. These divisions alternate with chambers in which zinc is placed in blocks. The chambers are filled with water, and the carbon compartments are sealed up. The current is generated by admitting more or less chlorine gas into the carbon cells, and which circulates throughout all the cells. The electromotive force is said to be above two volts. The cell only calls for attention at long intervals, to make up for loss by evaporation, and to renew the zinc blocks. The chlorine gas is generated separately. For this purpose manganese and hydrochloric acid are used. The acid is admitted upon the manganese as required, the gas coming off as long as any strength remains in the acid. The gas is usually stored in a gas-holder, and its production need only be carried on at intervals. This appears to be an admirable battery for laboratories.

Portable Electric Light Batteries.

The peculiar difficulties presented by the oil and candle lamps employed by miners have led to the introduction of electric portable lights, giving an illumination of one or two candles, and fed by primary and secondary batteries. Hundreds of these are now in use in coal-mines in this country.

Walker's Portable Miners' Electric Lamp. — Mr. Walker has produced an ingenious application of the bichromate battery in his portable lamp. In one form of this apparatus the containing vessel of the battery is of carbon, forming the negative element. The vessel contains a porous cell, with the zinc. Various excitants may be employed, the most generally useful being a solution of bichromate of potash for the carbon cell, and dilute sulphuric acid for the zinc. The cover of the battery is composed of rubber, having the connections passed through it so as to avoid corrosion. A second cover surmounts this, and a suitable handle is mounted upon it. The lamp, which is a small glow-bulb of a few candles' capacity, is fixed before a reflector upon the front of the case, and the whole emits a light sufficiently strong to permit of the reading of a newspaper at 6 ft. from the lamp. Its duration without recharging is ten hours. It weighs 5 lbs., and its cost of running is said to be ¾d. per day.

Friedlander's Portable Electric Lamp.—This is another ingenious adaptation of the bichromate battery, in which only a single fluid is used. The elements used are carbon and zinc, and the excitant chromic acid in solution. The advantage of chromic acid is that it does not so readily permit the polarization of the cell; it is also more readily soluble than the bichromate of potash or soda; but it is more costly. The portable lamp is fitted up in an ebonite case 8 in. high by 5 in. square. There are five cells, divided vertically, with five pairs of zincs and carbons. These are so attached to a horizontal spindle at the top of the case that upon partially rotating it the pairs are raised to a horizontal position and clear of the liquid. They may then be lowered, more or less, according to the light required. The lamp is a Swan glow-lamp, taking eight volts and one ampère, and yielding four candle light. It is said that the cost of a fresh charge of the excitant costs three or four pence, and maintains the light for two and a half hours.

A large variety of such portable primary batteries have of late appeared. They are most of them based upon the elements already mentioned in the present chapter. There is a great variety of excitants all claiming some novelty or special advantage, but these are scarcely of sufficient interest to demand further attention.

Secondary Batteries or Accumulators.

When we pass an electric current through a cell composed of two plates of platinum plunged in dilute acid, a result ensues which may be assumed to be the storing up of a certain percentage of the electric energy. That an accumulation of electrical force (or force capable of becoming electrical) has actually taken place may be demonstrated by disconnecting the secondary cell and closing its circuit through a galvanometer. A powerful rush of current is at once indicated, having a direction opposed to that of the primary current. If we examine the plates while still in the condition of electrical accumulation, it is found that a portion of the water has been decomposed into its constituents, the gases being deposited as a layer, or cushion, upon the two plates. The oxygen appears upon the positive plate, or that by which the current enters the cell, and the hydrogen upon the negative plate, or that by which the current leaves the cell. The hydrogen film is found to be electro-positive to the oxygen film, and a certain amount of potential energy is conferred upon the two cushions of gas, so that when we connect the plates by a conductor it is ready to become free in the form of a current, and so restore the equilibrium of the two films, which become recomposed into water, and the cell is once more at rest.

A German physicist, named Ritter, was the first to construct a battery from which these secondary currents could be obtained. In 1859 M. Planté discovered that sheets of lead yielded effects of considerably greater duration than those obtained from plates of platinum, which was usually employed by Ritter. He also discovered that by continuing the charging current for a sufficient time a peroxide of lead was formed upon the positive or oxidised plate, and hydrogen was deposited upon the negative plate. It was found that when this stage was reached the charge accumulated by the cell was very considerable, and that the element possessed a much higher electromotive force than any of the ordinary voltaic generators. M. Planté also found that in the course of the yielding up of the energy stored the oxidised plate became deoxidised, and that its oxygen passed through the liquid to the negative plate, attacking and oxydising it. The positive plate, which had thus been oxydised and become deoxydised, presented the appearance of spongy lead, and so offering an enormous extent of surface to the action of the current. Each time the cell was used its capacity for storing electric energy was increased, until both plates were in the spongy state, and the accumulator had attained its fully *formed* condition, as it was termed.

These observations led M. Planté to considerably extend the surfaces of the lead plates employed in the cells. He next placed canvas between two large, thin plates and rolled them up in a close spiral. They were thus separated by a short space, but insulated from each other. The spiral cylinder was then plunged in dilute acid, and the charging current passed for some time. The cell was then discharged and the current passed through it as before, but in the opposite direction; again discharged and allowed to rest for a day or two, until the oxide formed had time to become rigid. The operation of *forming* the cell thus extended over some length of time, and its capacity for storing electric energy increased with each recharge. When once fully formed, the cell had only to be connected to a pair of suitable voltaic batteries to receive a charge of considerable power, which might be carried about and used at pleasure. The advantage of this secondary cell consisted in the powerful current it evolved, with a low internal resistance and of high electromotive force.

M. Faure, in 1881, turned his attention to the possibility of still further extending the valuable researches of M. Planté, and acting upon the hint afforded by the fact that in the Planté cell a peroxide of lead had formed upon the plates, and that its thickness partly determined the capacity of the cell, tried the effect of coating the lead plates direct with a thick cushion of *minium*—a kind of red-lead. This peroxide was mixed into a thick batter with dilute acid, and the plates so treated were separated by cloth or felt, and rolled up in a spiral or arranged in rectangular troughs. The result was not only a combination which was at once ready to receive a charge, but it possessed the advantage of having a greater accumulative capacity than the first cells of M. Planté. This ready method of forming the cells gave great impetus to the development and employment of secondary or storage batteries, and to the introduction of many other forms of voltaic accumulator.

Development of the Accumulator.

Further experiments led M. Planté to the conclusion that a large portion of the time required for "forming" the cell might be saved by treating the plates at the outset with a dilute solution of nitro-sulphuric acid; the object aimed at being to render the plates porous, and so obtain a greatly extended surface for the current to act upon. The result of these experiments has been to reduce the time required for forming from weeks to hours.

Various inventors took up the development of the accumulator, and in the hands of Sellon, Volkmar, Swan, Julien, Parker, &c., it has become a combination of great importance.

It was found that the method of Faure, in laying a coating of minium upon the plates, gave rise to subsequent inconveniences. The acidulated water rotted the canvas or blanket partitions, and the coatings fell away. Mr. Swan conceived the idea of making the lead plate in the form of a *grid*, and pressing the red-lead paste into the perforations, so dispensing altogether with the necessity for coatings or continuous separators of any kind. Mr. Parker, finding that the paste was apt to break away and fall to the bottom of the cell, formed a plate with numerous perforations, countersunk at each side, so that the oxide plugs might retain a better hold, Fig. 19. Mr. Moseley and others invented "separators," consisting of thin ebonite sheets, corrugated and perforated, and studs of vulcanised rubber inserted into the plates, so as to form separators at intervals without impeding the circulation of the liquid.

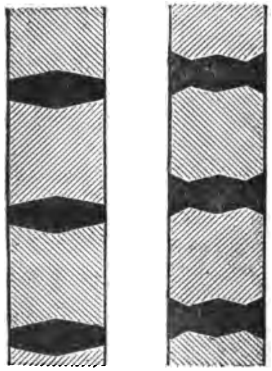

OLD TYPE GRID (SECTION). NEW TYPE GRID (SECTION).

Fig. 19.—Grids (greatly magnified).

Thus formed, the secondary battery became a practical every-day auxiliary to the dynamo for regulating purposes, transforming from one tension to another, higher or lower, for train lighting and for moving tramcars.

But fresh difficulties arose in the working. It was found that, after a time, if the cells had been carelessly treated, the ordinary solution, consisting of water raised to a density of 1·150 with sulphuric acid, gave rise to the formation of coatings of the white sulphate of lead. This defect, which speedily clogs the action of the cell, was known as "*sulphating*."

Mr. Barber Starkey, in 1886, in the course of his experiments, discovered that the addition of soda to the solution was extremely beneficial, and prevented the sulphating without any accompanying disadvantage.

Mr. Preece made a series of experiments with the new solution in order to determine the best proportions. He found,* after careful trials, that of five solutions of the following proportions:—

No. 1.—5	pints sulphuric acid,	5	pints sulphate of sodium,	15	pints water,
No. 2.—5	,, ,,	4	,, ,,	16	,,
No. 3.—5	,, ,,	3	,, ,,	17	,,
No. 4.—5	,, ,,	2	,, ,,	18	,,
No. 5.—5	,, ,,	1	,, ,,	19	,,
No. 6.—5	,, ,,	to 20 pints of water,			

No. 5 gave the best results. The sulphate of soda solution was made by dissolving carbonate of soda (common washing soda) to saturation, and adding thereto sulphuric acid until effervescence ceased. The solution is easily made up as follows:—To a quart of saturated carbonate of soda solution add slowly, during continuous agitation, 12 fluid ounces of strong sulphuric acid. Fill the cell with water 19 parts, strong sulphuric acid 5 parts, soda solution 1 part; total 25 parts. The specific gravity of this electrolyte should be 1·210.

On the Continent and in England there are several makers of secondary batteries whose products are so near perfection as to be available for a great variety of purposes. They will stand charging and discharg-

---

* "Journal of the Society of Arts," May 3, 1889.

ing for many years without showing much sign of deterioration.

Both Messrs. Elwell Parker and the Electrical Power Storage Company make cells adapted to every purpose where accumulators may be used. The latter company construct their "E.P.S." cell according to various patterns, for stationary purposes, train lighting, tramcars, and for use aboard ship.

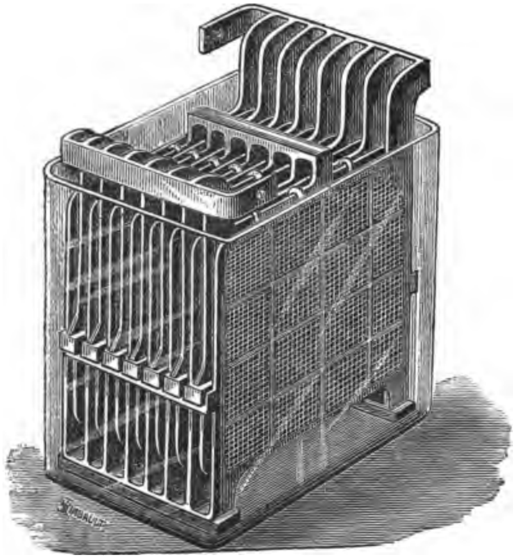


Fig. 20.—Cell of the E.P.S. Type.

Fig. 20 exhibits a cell of the E.P.S. type, used for stationary purposes. The plates of the cell are divided into positive and negative, a pure lead grid with perforations as in Fig. 19 being cast so as to retain the paste. Each plate is 8½ by 9½ by $\frac{3}{16}$ in. thick and weighs 5 lbs. The positive grids have the perforations filled with a stiff paste of minium. Those of the negative grids are filled with litharge. The plates are arranged in close proximity in the cells, being kept apart by vulcanite separators or rubber studs. It is not found advantageous to place the plates very close together, but to give space enough ($\frac{3}{8}$ inch) for free circulation of the electrolyte and to diminish the chance of short-circuiting.

All the positive plates are *burned* (not soldered) in contact with a common junction piece of lead and the negative plates with a similar piece, forming the poles. The containing vessels are usually glass. When the cell has received its electrolyte it is connected in a suitable series of such cells and the process of charging is commenced.

The electromotive force of the dynamo required to charge cells must always be rather in excess of the E. M. F. of the cells themselves. Thus, the E. M. F. of a secondary cell is a little over 2 volts. Hence, to charge ten cells, the dynamo must give not less than 22 volts. It is usual to allow a still greater E. M. F. or 2·4 volts per cell. The current may vary somewhat, but it is seldom less than 10 ampères. Given this current and an E. M. F. of about 10 per cent. above that of the battery, and any number of cells can be charged simultaneously. The grouping of the cells is, of course, frequently made to suit the E. M. F. of the dynamo. Thus a dynamo giving only 12 volts and a current of 20 ampères would charge a 10-cell battery of accumulators arranged in two groups of five, joined in parallel.

Charging may be accomplished still more rapidly by more powerful currents than the above, but, as in discharging, if the rate is high the cell is rapidly destroyed. This condition is known as over-working, and is to be avoided if the battery is required to keep in good condition.

The result of connecting the litharge (positive) plate with the positive pole of the dynamo, and the minium (negative) plate with the negative pole, and passing the current for several hours, is to reduce the former substance to *spongy lead* and the latter to lead peroxide (PbO_2). Upon disconnection the battery will give an E. M. F. of about 2·2 volts per cell, but after a time this falls to 2 volts, and remains fairly constant to the end of the charge.

To light standard 50 volts incandescence lamps a battery of about 27 cells is usually employed. The size of the cells depends upon the number of the lamps and the time the current is required. Thus one lamp only will require the whole E. M. F. of the 27 cells.

Capacity of the Cells.—Secondary batteries are said to have a capacity, or rate of discharge, of so many *ampère hours.* Thus, a small cell, having 32 lbs. of plates, each 9½ by 8 by 2 inches, will give a discharge at the rate of 1 ampère for 50 hours, or a capacity of 50 ampère hours. The capacity of a cell is the amount of electrical energy it will receive and restore. The maximum rate of discharge from the above cell would be about 9 ampères.

Efficiency.—This depends almost entirely upon the rate of discharge. If the cell is discharged slowly—that is, through a suitable resistance—its efficiency, or the ratio of discharge to charge, may be as high as 95 per cent. If, on the other hand, it be rapidly discharged (through a small resistance) it may fall to 50 per cent. Hence, some judgment is necessary in working these cells to obtain the best results. Several authorities put the general maximum useful rate of discharge within 10 hours.

A very important element in arriving at the value of an accumulator is the amount of energy that it will receive and yield per pound weight of lead plates. The best cells now made give 4 ampère hours per lb. of plates. This is the rate for pure lead grids packed with minium and litharge as described. By lightening the plates, as for traction purposes or launches, as much as 5 ampère hours can be got. But this is equivalent to shortening the life of the cell. In the earlier batteries of Planté, where the plates are *formed* entirely by electrical means, a great deal of lead remains unreduced, and the rate is often not higher than 2 ampère hours per pound of plates.

Cells for Ship Lighting.—When secondary cells are used on shipboard, or anywhere in motion, they are usually constructed in lead lined teak boxes, made deep in proportion to the depth of the plates, a perforated screen being placed directly above the plates.

Treatment of Accumulators. — In charging cells several methods of indication that the battery is charged are in use. The most common one, though it is rather unreliable, is to observe the appearance of the solution. When the cell is fully charged this becomes of a white milky appearance, owing to bubbles of gas that cannot freely escape. Another plan is to find the specific gravity by hydrometer, which increases very considerably up to about 1·220. But the most reliable test is the E. M. F., which, upon connection with the voltmeter will indicate between 2·4 volts to 2·7 volts when a powerful charging current is used. The ascent above 2 volts is rather sudden when once the full charge is taken.

The life of an accumulator depends almost entirely upon its treatment. It should be examined very frequently. In many successful installations the examination takes place twice or thrice a week. Any buckling of the plates, or falling out of pluggings, especially if resting between plates, should be at once remedied. The solution should be periodically tested, and kept at 1·220 when fully charged. This falls about ·1 for every 5 ampère hours; and when the density falls to 1·150 the cells are exhausted. *Secondary batteries should never be worked to exhaustion.* The density must be made good from time to time, from 1·150 when empty, upwards in proportion to the charge.

Cells should be tested individually. When a test of the whole battery shows a loss in E. M. F. each cell should be tested by itself to discover the faulty point. A faulty cell should be removed, taken apart, faces of plates cleared, straightened, solution filtered, &c.

The life of the positive plates, under good treatment, is probably over three years. The negative plates do not deteriorate so fast, and may last from seven to twelve years.

A very interesting question in connection with the accumulator is the period for which a cell will retain its charge. This would appear to depend greatly upon the insulation of the cell. With glass cells, varnished, or coated with vaseline or paraffin wax, and insulated upon porcelain cups, the loss from leakage is very small. The insulating cups are generally filled with a little resin oil, and one of these is placed under each corner of the cell. Instances are common in which the charge of a cell has remained unimpaired for three or four months, and there appears no reason why it cannot be retained indefinitely.

The accumulator is now largely used for portable lamps, such as for mines, travellers, and for theatrical purposes. A small accumulator, weighing three pounds, may in this way be made to light a small incandescent lamp for ten or twelve hours, yielding a light of two or three candles.

Accumulators are also likely to be largely used in the future in connection with central stations for lighting They serve, in a measure, the purpose of a gas holder in a gas works. By their use the engine power may be reduced to a minimum, for it may work throughout the twenty-four hours, whereas when the supply is taken direct from dynamos the whole current is only required during certain hours, and more than two-thirds of the time the engine power is practically idle. As a reserve in case of accidents, the accumulators are also extremely useful. But many arguments are urged against them. First, their great cost; their rate of deterioration (15 to 20 per cent. per annum); and the attention they require, &c. On the other hand, steam power and dynamos have been made more and more perfect, and it is a burning question whether it is best to provide a reserve in steam power and dynamos or in secondary batteries.

With reference to this point the reader is referred to an excellent paper, followed by a discussion, read before the Institute of Electrical Engineers, April 12, 1888, and printed in the Proceedings of the Institute.

CHAPTER III.

THERMO-ELECTRIC BATTERIES.

THE possibility of being able to discover an arrangement of metals which, by the aid of heat, would evolve electricity economically, has led many of our first inventors to devote much attention to the problem.

A current of electricity is produced in a circuit composed of two different metals when their junction is heated. The metals which exhibit this property to the greatest degree are bismuth and antimony. If two bars of bismuth, B and C, and one of antimony, A, are placed as in Fig. 21, and heat applied at one junction while the other is cooled by radiation or otherwise, a current will flow into the wires and through the galvanometer.

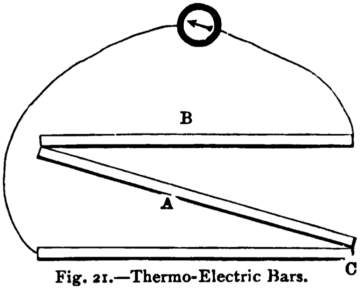


Fig. 21.—Thermo-Electric Bars.

The two most efficient thermo-electric piles in use up to 1876 were probably those of MM. Clamond and

Nöe; great numbers of such pairs being employed to multiply the force and current.

By the expenditure of 21 lbs. of coke per hour, M. Clamond, of Paris, has succeeded in maintaining four electric lights, each having an illuminating power of 220 standard candles. This is vouched for by the Count du Moncel; and, indeed, there should be nothing impossible, or even difficult, in the accomplishment of such a result. Sixty couples will yield, when well constructed, a current equal to a gallon Bunsen cell, and less than 3,000 elements will give the effects of 50 Bunsens with an expenditure of 80 cubic feet of gas per hour. Such results are reported of the couples of M. C. A. Faure.

M. J. E. M. Sudre, who has been working in conjunction with M. Clamond, has taken out a patent for the following advances in the make-up of thermo-electric batteries.

1. For the construction and arrangement of thermo-electric chains composed of couples, the resistance of which has been reduced to a minimum.

2. The combination and arrangement of the chains with two metallic plates, of which the opposing surfaces are coated with an insulating layer; which plates form part of two metallic systems, one serving to collect and communicate the heat, and the other to abstract and diffuse it.

3. The combination and arrangement for binding coupling, and insulating the thermo-electric chains, when several are mounted side by side between the two plates.

4. The application and use of the collector and diffuser to any description of thermo-electric piles, so as to maintain the necessary difference of temperature

between the extremities of the couples without lateral waste of heat.

One of the main features of the invention, as described, is the maintenance of the necessary difference of temperature between the two solderings of each couple by placing those couples between two surfaces from which they are electrically insulated. It is stated that in the construction of thermo-electric couples and chains, an isolated thermo-electric couple is ordinarily composed of a prism in metal or alloy casting and of a plate of iron, copper, German silver, or other suitable metal soldered to each of its extremities. The plates do not ordinarily interfere in the slightest with the electric force obtained, and it is the bar, such as that of antimony and zinc, which produces the effect.

When it is desired to use two metals or energetic alloys of which the effects are combined, and which are easily fusible, such as bismuth and antimony, the couple is then formed of two bars, which are joined together by a cross bar which binds them and is soldered to each of them.

The total resistance of a couple is composed, 1st, of the resistance of the connecting plate; 2nd, of the resistance of the bar, ordinarily composed of alloys sufficiently resistant; and 3rd, of a particular resistance at the points of contact or soldering between the plates and the bar. The metallic plates should be of a metal sufficiently conductive, such as copper, iron, German silver, &c., and should be sufficiently large and thick to present but a feeble resistance. They should also be as short as possible. These conditions, it is claimed, are realised in the improvements of M. Sudre. Again, the bar should have very little resistance under a small volume. The inventor takes as a datum the formula $R = k\frac{L}{S}$, in which k is a specific coefficient for the metal employed, L the length of the bar, and S its section. As the resistance depends on the ratio $\frac{L}{S}$, the volume of the couple may be diminished by diminishing the length and sectional area in equal degrees, in which case the resistance will not be affected.

The length which should be given to the bar depends upon the difference of temperatures employed. For differences of temperature between 10° and 120° (Centigrade), M. Sudre gives to the couples a length of 10 or 12 millimètres, whilst if the higher temperature reaches 300° the length varies from 20 to 30 millimètres. The resistance at the points of contact or soldering is of the highest importance. The junction should be made so that the plate is in contact with the whole section of the bar. The plate should penetrate to a very little depth within the bar, so as not to diminish too much the electromotive force of the couple; for the really effective difference of temperature is that of the two solderings, and this difference diminishes as the plates penetrate more deeply into the bar, and thus approach one another.

In constructing the couples M. Sudre cuts the extremities of the connecting plates in the form of a comb, the teeth of which are afterwards twisted so as to present a helicoidal surface, which holds the plates, as it were, screwed into the bars. The cut portion of the plates is so adjusted in a mould that the teeth become embedded in the bar when this is cast. A considerable number of bars are cast simultaneously, and constitute a thermo-electric chain. The external portion of the plates is coated with asbestos-paper, mica, terra-cotta, or other suitable insulating material, which may be cemented to the metallic surfaces by means of silicate of soda solution.

The chains are arranged in battery between two metal plates, which may be plane or curved. Each of the plates is kept cool on one of its surfaces by means of a thin layer of some bad conductor of heat. One of these plates constitutes the collector and the other the diffuser. In order to maintain the diffusing surface at a low temperature, M. Sudre employs a cooling-box of water, fed from a tank.

CHAPTER IV.

MAGNETO-ELECTRIC GENERATORS.

IN the year 1831 Professor Michael Faraday made one of those brilliant discoveries which have immortalised his name, and has formed the starting point of all those ingenious electro-mechanical engines of the present day for converting the energy stored in fuel into light.* Arguing that as from electricity in the electro-magnet he obtained magnetism, so from magnetism there must be a means of obtaining electricity, he experimented with his usual skill and patient perseverance, and was rewarded by the discovery of what has been termed magneto-electricity. He found that if a magnet was moved near a coil of insulated wire forming a circuit, a current of electricity was induced in the circuit during the movement of the magnet.

Fig. 22 illustrates, in a simple way, the manner in which the generation of an electric current may be brought about by means of a magnet and coiled wire, with a galvanometer, or current measure, to prove its existence. A is a bobbin of insulated copper wire, having attached to its ends, or in circuit, a common galvanometer, B. When a permanent steel bar magnet, C, is quickly passed into the coil by the central aperture, a current is caused to circulate in the wire,

---

* "Philosophical Transactions of the Royal Society," November, 183

and its direction will be indicated by the direction in which the galvanometer needle moves. This current is, however, only momentary, that is, it lasts just as long as the magnet is in motion within the coil, and ceases as soon as the motion ceases. If, however, the magnet is now withdrawn, *another* current will be caused to circulate in the coil, and its direction will be opposite to that of the first. This will be shown by the needle of the galvanometer, B, being deflected to the left.

This simple experiment contains the first of all the laws of magneto-electric induction, and exhibits the fundamental principle of every dynamo-electric machine.

Were it possible or practicable to make the magnet move backwards and forwards within the coil rapidly by means of any mechanical contrivance, we should have a magneto-electric machine on a small scale. The currents would be alternating in direction, just like those from the machine now used to burn the "electric candles," and would be induced in the coil just as long as the motion was kept up.

The necessary materials for the practical illustration of this important principle may consist of a paper bobbin 3 inches long, wound with five layers of No. 22 B. W. G. cotton- or silk-covered copper wire; a galvanometer or current detector, composed of a magnetised sewing-needle, suspended at its centre by a thread, within an oblong coil (say ten turns) of the wire. The needle must, of course, be held parallel with the wire coil. A steel bar magnet of the common kind, and 8 inches long, will complete the apparatus practically as exhibited in Fig. 22.

The effects produced are due to what is termed *magneto-electric induction*. It is more difficult to move the magnet in the coil when the circuit is closed than when it is open. The action that takes place may perhaps be explained as follows:—The movement of the magnet induces a current in the coil, forming it into a magnet with its poles in a position such as to attract the poles of the moving magnet in the reverse direction to that they are moving in, and thus opposing the motion of the magnet. This opposition has to be overcome by force, and the energy thus expended, less that dissipated in heat, reappears in the form of current in the coil circuit. The magnetism thus forms a connecting link between the movement of the magnet and the current produced.

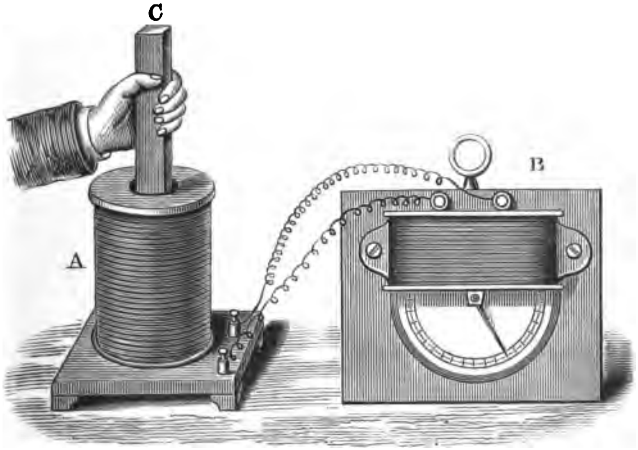


Fig. 22.—Induction Experiment.

Fig. 23 illustrates an experiment in *current* induction. Some electric generators have been constructed upon this principle; and they are amongst the most successful. It is important that the reader should understand, as bearing upon the whole art of dynamo-electric machine construction, that a bobbin A, coiled with wire and connected to a current detector B, has induced in it currents in opposite directions as the wire bobbin C, drawing current from the voltaic cell D, is moved up and down in it. The principle is identical with that shown by the first experiment, the connecting link between the energy and the current produced being, in this case, not magnetism but electricity itself. All that can be done by the magnet may be done with the current bobbin C.

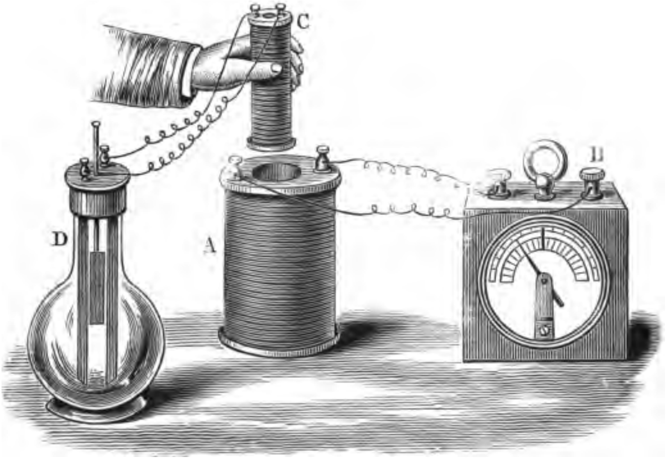


Fig. 23.—Induction Experiment.

The materials to illustrate practically this second phase of the first law may consist of the same larger bobbin and galvanometer, with a ruler, coiled with two layers of No. 22 wire, connected to one of the bichromate of potash cells already mentioned.

First Magneto-Electric Machine.—A year after the publication of Faraday's experiment, a magneto-electric machine was brought out by Pixii, who caused the magnet to revolve its poles near to the iron cores of a pair of bobbins forming an electro-magnet. He, in fact, caused by mechanical means a permanent magnet to induce currents in the wire of an electro-magnet.

It comes to exactly the same end, whether the electro or permanent magnet is moved. Saxton, in 1833, improved the arrangement; he placed the whole apparatus horizontal, fixed the compound horse-shoe magnet, and rotated the armature in front.

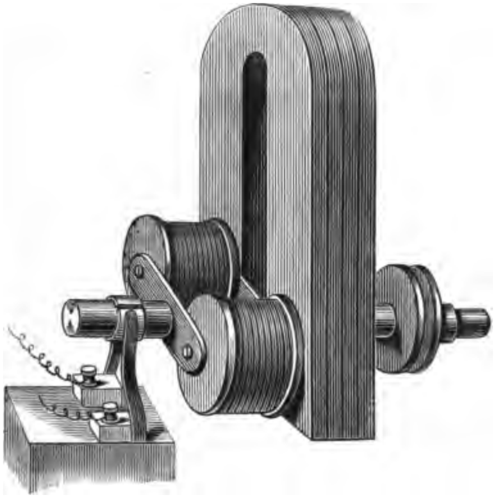


Fig. 24.—Clarke's Machine.

E. M. Clarke, in 1836, designed the construction exhibited in Fig. 24. He placed the magnet vertically and revolved the coils about a horizontal axis, and added a commutator to make the currents flow in one direction, which we have endeavoured to make plain in Figs. 25, 26.

In Fig. 25 are shown the two halves of a metallic cylinder, insulated from each other by some non-conducting material. A A are two contact springs for collecting the currents. Let us suppose that a constant current is being supplied to the two halves of the cylinder; in this case, as long as the cylinder remains in the position shown a direct current will pass to the springs, but if the cylinder is turned half-way round, the current will flown in the opposite direction in the springs, because the ends of the circuit connected to the cylinder remain the same, and communicate now with reverse springs. This is supposing a current in one direction, and as long as the cylinder rotates, the current will be reversed at each half turn. The machine, Fig. 24, however, gives alternating currents to the cylinder, and as these currents change direction just at the point where the commutator reverses, it is obvious that the alternating currents will now be made to flow in the springs always in one direction.

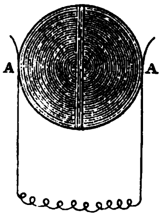


Fig. 25.—Commutator: End.

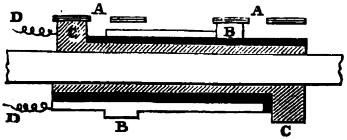


Fig. 26.—Commutator: Section.

In practice, the common commutators are made like B and C, Fig. 27, which shows Stöhrer's machine of 1836. B is a cylinder, an explanation of the construction of which is given in Fig. 26, and C is a pair of forked contact springs. A and A in Fig. 26 represent the ends of the pair of springs C, just spoken of, and the cylinder is made up as shown in section. There are two metal tubes on the spindle, and they are insulated from each other by a tube of ebonite or wood, shown black. The metal tubes are connected to the wire coils as exhibited. Reverting to Fig. 26, B and C are projections on these tubes. They extend half round the circle, B and C (bottom) on one side, and B and C (top) on the other. At each half revolution, therefore, as the coil changes the direction of its current, so do the cylinder and springs, the result being a constant current in one direction. The current is necessarily strongest just as the coils, with their iron cores, pass the poles. In these machines, therefore, we have simply an electro-magnet revolved before the poles of a permanent magnet.

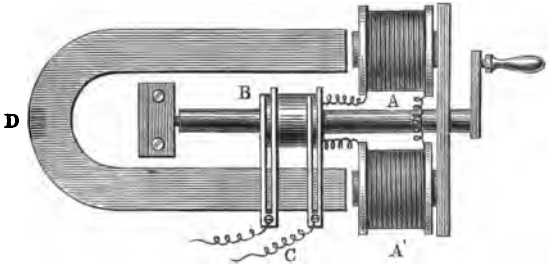


Fig. 27.—Stöhrer's Machine.

Clarke's machines are usually employed for medical purposes, and as no shocks would be felt upon grasping handles fixed to the wire ends were the currents continuous, it is usual to arrange an interrupter in the circuit. This may be done either by employing a third spring, working on a brass tube split, so as to give a break of circuit, at its centre, or by making the half-rings in Fig. 26 overlap on the tube—that is, making them slightly pass the central line. The result will be that the current at each half-turn will pass for an instant by the fork of the spring, so cutting it for the same period of time from the exterior portion of the circuit.

CONSTRUCTION.

Concerning the practical construction of these machines, it is not our intention to dwell upon it at great length, on account of their simplicity. It will, however, be useful to state that the iron used in these revolving electro-magnets, as *cores* and *yokes*, should be as soft and pure as possible, so that it may with rapidity change its magnetical polarity. Hard iron will develop only weak currents. The material usually employed is Swedish iron, made soft by soaking in a blood-red fire for some hours, and then cooling very slowly by burying in the hot ashes or allowing the fire to go out. The parts of iron to be screwed together must be quite clean, and in order to secure a good connection they should be quite flat.

The size and number of layers of *wire* must be regulated by the purpose for which the machine is intended. If high electromotive force be required, as for an electro-medical machine, the wire should be fine, to give a great number of turns; but if the currents are required to do work in an external circuit of low resistance, a thick wire is to be employed. The electromotive force and resistance of that part of the circuit formed by the moving coil will depend upon the number of turns of the wire, and upon its size. The greater the number of turns, the higher the electromotive force, and the stouter the wire the less the resistance.

The amount of current or quantity passing in a given time in the circuit depends on the resistance of the whole circuit, as well as on the electromotive force; and, therefore, if the portion of the circuit external to the machine is of small resistance the wire of the coils should be large, and if the external circuit is of great resistance the wire should be small and have many turns.

The principle is to some extent analogous to that of the voltaic battery, for when the cells are increased in size the internal resistance of the battery is decreased, and if the external resistance is small, the decrease in the total resistance of the circuit thus obtained more than counterbalances any decrease in electromotive force. If the number of elements is increased the electromotive force is increased, and if the external resistance is great compared to that of the battery, this more than counterbalances the increase of the battery resistance.

It is important that this should be borne in mind as bearing on the voltaic arc. Great electromotive force will give a longer arc than a small electromotive force; but if we get very small internal resistance we can produce with a given electromotive force an arc which, though having a very small length, may, from the magnitude of the current passing, have a greater volume of light than with the greater length of arc. The exact relation, however, between all these elements of the question are not as yet entirely understood. Despretz, in a paper communicated to the French Academy, describes some experiments on the subject. He found that the length of arc increased more rapidly than the number of elements in series, and that by coupling given groups of batteries in parallel circuits (or, as it sometimes is termed, "for quantity") very small arcs as regards length were obtained, but the amount of light given is not stated.

CONSTRUCTION.

For medical machines, from No. 18 to 32 wire, cotton- or silk-covered, will answer, according to the tension required. No. 22 or 24 will usually be found suitable, and as many as from five to ten layers may be wound on the reels. All connections must be soldered to prevent bad contact, and care is necessary that the wire passes from one reel to the other like the letter S (A, Fig. 28), so that, in appearance, the winding may be in opposite directions. B, Fig. 28, exhibits the iron back and the coils.

Magnets of the permanent kind for such machines must be of good steel only. It is, indeed, imperative that the steel should be of the finest kind if the best effects are sought, and if it is required that the magnet should retain its force for many years. Steel of indifferent quality will soon become weak in magnetism; that known as "tungsten" steel is the best.

The soft steel should be heated to a dull red, and then curved into the horse-shoe shape required. It should then be finished up, and again heated to a blood-red and plunged, bend first, in cold water or oil. This should make it so hard that a file will not act upon it, when it is ready for magnetisation. In order that the steel may absorb the maximum of magnetisation, it is usual to reduce its hardness at this stage to a slight degree by plunging it in a bath of melted lead or tin, the temper being observed by the colour produced. The steel may be magnetised by a permanent or electro-magnet larger than the new one, or by a few cells of the strong batteries, such as the bichromate or Bunsen. In magnetising by battery, the legs must be coiled with insulated wire. Four layers of No. 16 will be sufficient on each, and one minute of passing the current will suffice. The circuit should be broken two or three times during the operation. The process of magnetising by a magnet is by rubbing it upon the steel, pole following pole, from end to end, in one direction. A piece of soft iron must cross the poles of such magnets when not in use or while being magnetised.

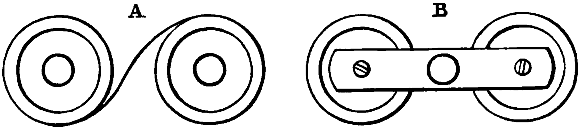


Fig. 28.—Electro-Magnet.

Large Magneto-Electric Machines.

Some eighteen years passed without any great advance being made in the use of magneto machines, or any increase in their size, although several patents were taken out, some of which we shall have to allude to farther on.

The "Alliance" Machine.

In 1850 Professor Nollet, of the Military School of Brussels, commenced the design of a powerful magneto-electric machine, with the view of decomposing water and procuring oxygen and hydrogen for the lime light. In 1853 a company for this purpose was formed in Paris called the Société Générale de l'Electricité, and a large machine by Nollet was experimented on in Paris. The experiments failed as regards the lime light, but experiments on the electric light made by Mr. F. H. Holmes with this machine, altered to a continuous current machine by means of a commutator, were so far successful as to lead to further experiments both in France and England. About 1859 the Compagnie de l'Alliance was formed for the manufacture of electric light machines. In the machines made by this company the commutator of Holmes was removed and the alternate current again adopted, and the machine was known as the "Alliance Machine," Fig. 29. Mr. Van Malderen had much to do with the success of these machines, which were used afterwards in the French lighthouses. From what was known when this machine was invented it was not possible, perhaps, to produce a better magneto-electric generator.

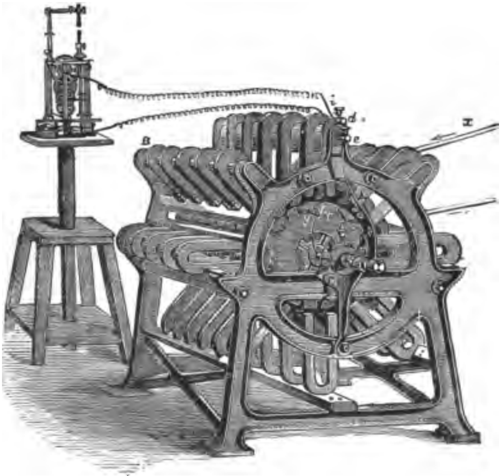


Fig. 29.—The Alliance Magneto-Electric Machine.

To a central shaft is made fast a series of copper or bronze discs, carrying each at its outer edges as many as 16 coils of wire with iron cores. The whole of this system, which may consist of as many discs as may be required, is caused to revolve by attaching the central shaft to a steam-engine. To an outside frame is secured a number of compound steel magnets; 8 sets of magnets are provided, and the coils revolve between each pair of magnet poles. The actual construction has been varied many times.

The currents given off are collected, one sign from the axis and the other from a brass ring upon, and insulated from, the axis. Alternate currents are of course produced, and as there are as many changes of direction as coils, the machine gives 16 alternate currents per minute; the shaft being driven at 400 revolutions, there must be at least 6,000 to 7,000 alternate impulses and changes of direction per minute.

As a matter of course, the parts, on account of these rapid magnetic reversals, become heated, but the way in which the parts are arranged causes them to act as a wind fan, which although it absorbs some power, keeps the machine cool enough for continuous working.

It was a modification of this class of machine which first illuminated the south lighthouse at Cape La Hève, in 1863, and the same apparatus, slightly improved, was put down at the north lighthouse in 1865. Two 8 horse-power steam-engines drive a pair of the machines at each lighthouse. The light from one is equivalent to 1,900 candles. The same kind of machine is fixed at Cape Gris-nez.

The Holmes Permanent Magnet Machines.

Mr. Holmes gave further attention to the subject, and in 1857 a large machine, made under his superintendence for the Trinity Board, was experimented on at Blackwall under the direction of Professor Faraday. In this machine the magnets, 36 in number, mounted on six wheels, rotated, and the coils were fixed and arranged in 5 rings of 24 each. The currents were made direct by means of a commutator.

The experiments were satisfactory, and two larger machines were made for the South Foreland lighthouse. In these machines the magnets were fixed and the coils rotated as in the earlier Alliance machine. The machine contained 60 compound horse-shoe magnets mounted radially in their vertical planes, the poles of the magnets being turned away from the centre. The coils, 160 in number, were mounted upon two wheels about 9 feet diameter, 80 to each wheel. By means of a commutator direct currents were obtained. The power absorbed was 2¾ horse-power to each machine. On the 8th of December, 1858, the electric light produced from permanent magnets was shown on the sea for the first time at the South Foreland high lighthouse. These machines were afterwards removed from the South Foreland lighthouse and placed in Dungeness lighthouse, where the light was exhibited in February, 1862. Another machine was made by Holmes in 1867, afterwards used at Soutar Point lighthouse in 1871, in which the magnets were fixed, but turned with their poles towards the centre. There were in this machine 7 rings of 8 magnets each, and between the rings of magnets revolved 6 wheels on the shaft, having 16 coils each. This machine had no commutator, and the alternate currents were taken off by brushes. It is, in fact, nearly a return to the Alliance machine, viz. permanent magnets, horse-shoe magnets turned with their poles towards the shaft, the coils revolving, and no commutator. Professor Holmes afterwards designed other machines which do not belong to the permanent magnet class, and will be described farther on.

The Siemens' Armature.

In 1856 Dr. C. W. Siemens patented an armature of great merit for magneto-electric machines, and which has been, and is still, extensively used in magneto machines of various descriptions. It consists of a long iron bar, deeply grooved on two opposite sides, lengthwise. In this deep channel the wire is wound lengthwise of the bar, over its ends and along its sides. One end of the wire is soldered to the iron armature itself, and the other to a metal ring (insulated) on the driving spindle. This arrangement occupies the place of the electro-magnet in Clarke's machine, and it is rotated, by suitable means, *between* the poles of a powerful permanent magnet.

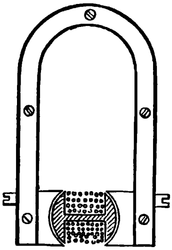


Fig. 30.—Siemens' Shuttle Armature.

Fig. 30, which will further explain this, exhibits a cross section of the armature, with the wire in position. The sides of the armature are solid and rounded. Two cheeks, hollowed out, are shown attached to the poles of the magnet. These embrace the armature, which revolves very closely to them. It is usual in practice to wind the wire until it nearly completes the circular form of the sides. Rings of brass are then put over all, to prevent the wire from being forced out of position by the force of rotation. The pole cheeks are long, to embrace a considerable length of armature. There is very little churning of the air, as in Clarke's machines. This form of Siemens' armature has been employed by Dr. Siemens in a magneto-electric machine, with a number of magnets arranged parallel to one another, and by several other makers, among whom may be mentioned Mr. Wilde, of Manchester, and Mr. Ladd, of London.

The armature, and several modifications of it, have been employed in magneto-electric telegraphic machines, and in the better class of medical apparatus. These forms of the machine do not, however, concern us here, although they are, historically, of much interest.

Pacinotti's Ring.

In the year 1860 Dr. Pacinotti devised a magneto-electric armature of peculiar form. It was first used in a machine made for the Physical Cabinet of the University of Pisa in that year. It does not appear, however, that Dr. Pacinotti published a description of his machine until the year 1864. The nature of the Pacinotti ring, as it is sometimes called, will be most readily understood by the description of Brush's armature, to be given further on.

Breguet's Machine.

M. Breguet, a well-known manufacturer of electrical apparatus in Paris, constructs a machine which is composed of a pair of large permanent steel magnets, passing between the poles of which is a shaft carrying a stout iron disc, upon the face of which is secured, at right angles to it, a series of iron cores wound with wire. These cores are so arranged that both magnets act upon them, one magnet upon their free ends, and the other upon the ends fixed to the iron disc.

The apparatus is simply an extension of Clarke's principle, but the number of bobbins admits of a continuous current being given off. The coils are joined up as a battery in series. As the system is caused to revolve, all the bobbins on one side of the poles will give off direct currents, while those on the opposite side will give off inverse currents. These currents are properly collected by a pair of springs at the changing or neutral line. The contact slips are disposed readily from the central parts of the disc, and to each strip are joined the two adjacent ends of each pair of coils.

There is no actual break of circuit during the revolution, because the contact springs are always bearing upon two or more of the radial slips.

On a large scale the machine would doubtlessly work very well, and is adapted for the rapid dissipation of heat generated by the magnetic reversals. But the same advantage is again a disadvantage, because the coils, being some way from the axis, act as a fan, and so consume power in churning the air.

C. F. Varley's Machines.

In the machines constructed upon the designs of Mr. C. F. Varley, actual, or nearly actual, contact was maintained between the armatures and the poles of the inducing magnets. The magnets themselves, together with the intermediate cores, surrounded by coils of wire, form a complete ring, link, or circuit of iron, or iron and steel. These permanent or inducing electro-magnets have their respective north and south poles continuously or nearly continuously closed, notwithstanding the movement of the armature or armatures; but the armatures, when rotated or moved to and fro along the iron or link, affect the direction of the currents.

In arranging a machine on these principles in the simplest and most elementary form, two horse-shoe magnets are placed opposite to each other, and between their poles are two soft iron cores, on which are wound coils of insulated wire. The poles of the magnets are placed, the north opposite the south. Together with these, which are the fixed parts of the apparatus (Fig. 31, A, B), an armature is employed, E, to which a reciprocating motion is given, which places it first in contact, or nearly so, with the two poles of one magnet, and then tranfers it to a corresponding position with respect to the other magnet. The faces of the magnets and of the armature may be grooved to increase the area of the surfaces in contact or in close proximity.

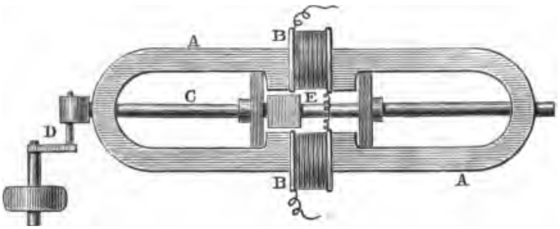


Fig. 31.—Varley's Machine.

In place of a reciprocating armature, a rotating one may be employed, so formed as to connect the north pole of one magnet with the south pole of the other, and, as it rotates, to couple the poles alternately.

In the figure a shaft is shown, C, reciprocally moved by the crank and power-pulley, D. In addition to this design of a dynamo-electric machine, Mr. Varley has invented various other pieces of apparatus for the production of single or multiple circuits of current.

M. Gramme's Magneto-Electric Machines.

M. Gramme, of Paris, introduced about the year 1871 what was considered at the time as an entirely new kind of armature, but which was afterwards discovered to have been invented previously by Pacinotti, as before alluded to.*

It is a *complete ring of iron*, and the wire is wound upon it without a break all round the circle. If an iron ring has thus wound upon it an insulated wire, forming a complete coil, the ends of which are connected by soldering together, and if this coil and ring are caused to rotate upon a central axis between the poles of a magnet, there will be developed in the coils a curious electric state. Two currents are constantly flowing in the wire, such that as each point in the circuit arrives at a spot equidistant from the two poles of the magnet, that point in the wire has a maximum positive potential, whilst the point in the coil exactly opposite to this has a maximum negative potential. If now the exterior turns of the wire are denuded of covering, and a pair of springs made to press, one on each side of the ring, on a line directly between the poles, a constant current, similar to a constant fall of water, will pass in any outside circuit connected to the springs.

---

* See list of dynamo machine patents, p. 170.

A Gramme ring may be made to work just as described, but in practice a different way of constructing the ring is adopted.

M. Gramme makes his ring armature up as shown in Fig. 32, where A and A are the ends of a coil or ring, composed of a great number of soft iron wires.

B B B are the coils of wire used by M. Gramme to cover the ring, it being found more convenient to make up the endless coil in sections, and then join them properly together, than to wind the wire from end to end and take the currents from the bared exterior. The upper part of the ring is seen fully coiled, while the lower side is being filled with coils. C C are the ends of the coils of wire, which are taken out for connecting up after the ring is complete. At D is shown a number of copper plates radiating from the centre, and having fixed to them, in notches and with soldering, the ends of the completed coils of wire. These radiating plates are simply for the purpose of carrying the currents along the axis to the point where they are taken off by a pair of contact pads or springs.

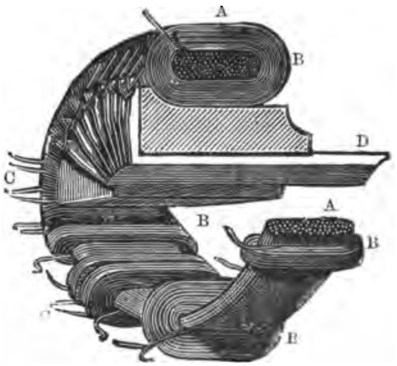


Fig. 32.—Gramme's Ring.

When the ring is complete, it is entirely covered with coils of insulated wire, and each coil is connected to a copper plate. The connection is made up, however, in this way:—No. 1 coil has its inside end connected to No. 1 copper plate, and to the same plate is connected the outside or commencing end of No. 2 coil. The outer end of No. 2 coil is then connected to No. 2 plate, and to the same plate is joined the outside end of No. 3 coil. This is continued around the circle, and the plates act exactly as if the wire was simply bared, and the currents collected direct. These radiating copper plates are also exhibited in the following views of the machine and its parts. The centre of the ring is filled up with a block of wood, or is driven by a brass spider-wheel, through which runs the central spindle, and into slits in which the copper plates fit. In Gramme's ring the iron wires forming it are not divided as represented in the figure. They form an endless hoop of soft iron, enveloped in an endless helix of insulated wire.

The length of wire in each coil will depend upon the size of the machine and upon the size of the wire. For No. 12 wire, well insulated, as much as 12 yards may be placed in each coil, and it is important that those coils are not very thick. They should be so thin as to allow about fifty to be placed on a 5-inch ring; but a great deal will depend upon the amount of care employed. Every part of the ring must be covered, and it will be found best, as convenient in making up the central space equal to the exterior, to coat the copper plates with gutta-percha and varnish at their outer edges, and to place them between the coils against the ring itself. Fuller particulars for actual construction will, however, be found further on.

Fig. 33 exhibits a section of the wire ring and coils, B B, upon a central spindle, C C. A A are the magnetic pole-pieces between which the ring revolves. It will be observed that there are lock-nuts to secure the central portion in position.

Gramme's magneto-electric machines are now manufactured by M. Breguet, of Paris, in two or three forms to suit hand-power. The machines are very useful in laboratories, where a powerful current of electricity is often required. The best type are those with Jamin's laminated magnets.

Fig. 34 is a view of this machine. It will be observed that, as in many other forms of the Gramme machine, the currents are collected upon the *neutral magnetic line*, that is, on a line passing between the poles of the magnet, vertically.

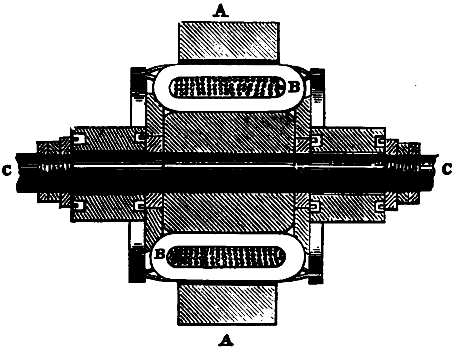


Fig. 33.—Section of Gramme's Ring.

Following are a few instructions by which the amateur may be enabled to make for himself a very useful hand magneto-electric machine. The construction is not difficult, and doubtlessly will be undertaken by very many in want of some clean and handy apparatus to supersede the troublesome and often unwholesome battery.

Fig. 35 represents a more simple form of the same machine, in which the magnet is composed of four or five sections, forming a compound magnet of considerable power.

The magnet is a permanent steel one. Some idea of the effect obtainable from the current, while the hand-wheel is driven about 80 turns per minute, may be gathered from the fact that 14 in. of No. 36 B.W.G. platinum wire is brought to a white, glowing heat in a few seconds, and the turning of the handle at a fairly uniform speed may be easily kept up for almost any time required in ordinary experiments.

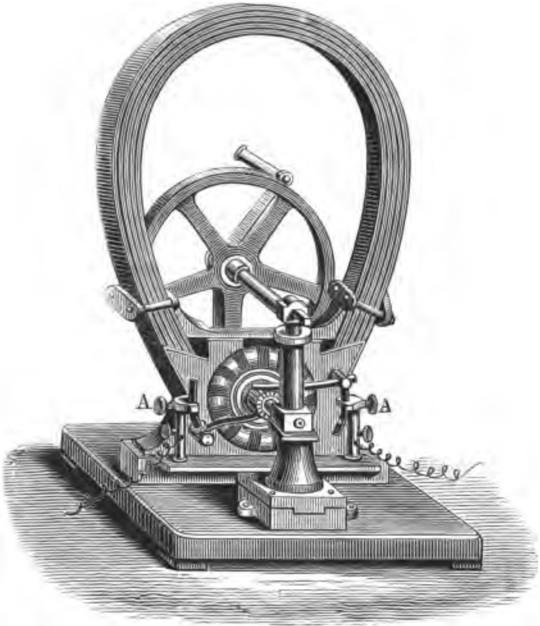


Fig. 34.—Gramme Hand Magneto-Electric Machine.

The general arrangement of the parts is indicated by the figure, in which M M is the permanent magnet, W the driving-wheel, gearing in a pinion on the spindle of the Gramme ring. Screws are represented on the face of the magnet. These are employed when the magnet is made of two or more sections or layers of steel. A solid steel magnet is used in the machine

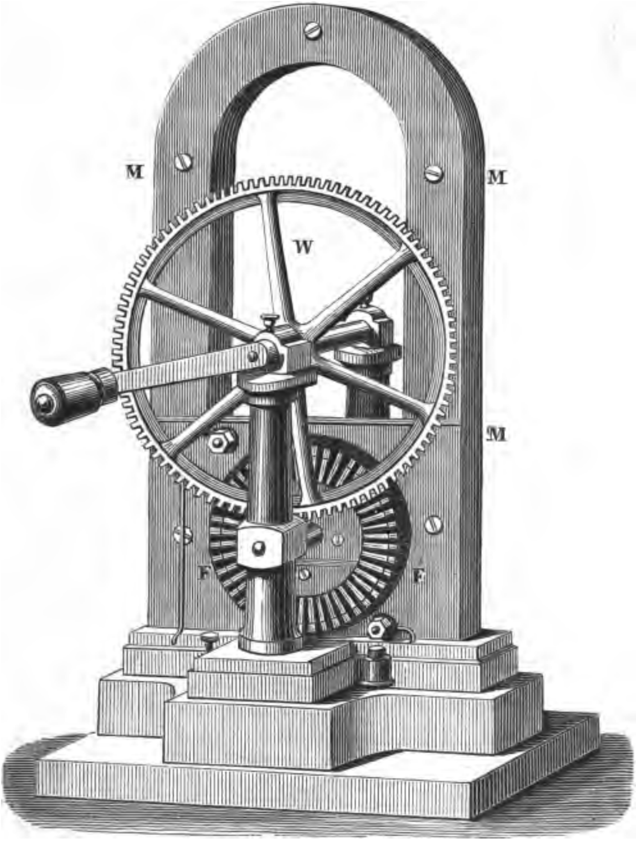


Fig. 35.—Gramme Hand Magneto-Electric Machine.

made by M. Breguet, but it is undoubtedly better to make it up from two or more layers, although in this case constructional difficulties are much augmented. The teeth of M. Breguet's driving-wheel are cut obliquely upon the circumference of the wheel. This is supposed to both decrease the noise and the risk of breakage; but the common wheel and pinion will be found to work the ring quite well. The base is solid, and it is imperative that it should be of some heavy non-magnetic substance, if the machine cannot be clamped or screwed to a table; this insures steadiness. The bearings or standards for the driving-wheel spindle also carry the ring spindle, and are of gun-metal. The driving-wheel may be of brass, as, although cast-iron would do, it is very apt to give way at the toothed portion; brass or gun-metal is therefore to be recommended. The magnet should be of the best steel only, because steel of indifferent quality will not only fail to take up sufficient magnetism but will lose its little strength in course of time. Even the best steel will, in a few years, lose some of its magnetic strength, but it is no difficult matter to re-magnetise it. The wire used in the construction of the ring should be of the softest iron procurable, and the wire from which the coils are made should be of good copper of high conductivity. A high degree of accuracy is not necessary except in the making up of the ring, which must be truly circular and somewhat equally balanced.

CONSTRUCTION.

The Magnet.—This part of the machine may be constructed in more ways than one. What is really required is a concentration of magnetic power at the ring-cheeks, *p p*, Fig. 36. Various forms of magnet might be employed to effect this, exclusive of electro-magnets; but as space in height is of little moment, and as the steel is most conveniently arranged vertically, the form of magnetic arrangement exhibited by Fig. 36 will be found to answer the purposes of the amateur best.

Fig. 36 represents the magnetic horse-shoe M M; the concaved cheeks, *p p*, may form part of the same mass of metal, but it will be found most easy in practice to make them of cast-iron, and to screw them to the magnet limbs as shown at the dotted lines on either side. The feet or basis of the bent bar should be attached by screws from underneath, on account of the difficulty of placing wire coils upon the magnet in the process of imparting the necessary magnetic strength. The length of the bar complete may be 3 ft., its width 3 in., and its thickness ½ in. It should be made from rolled steel, of flat bar shape, although any other shape of steel will answer the purpose. It is well to know, however, that if the thickness be greater than ½ in., the extra metal will be superfluous, for thick bars do not carry more magnetism than thin ones, and the difficulty of hardening will be greatly increased.

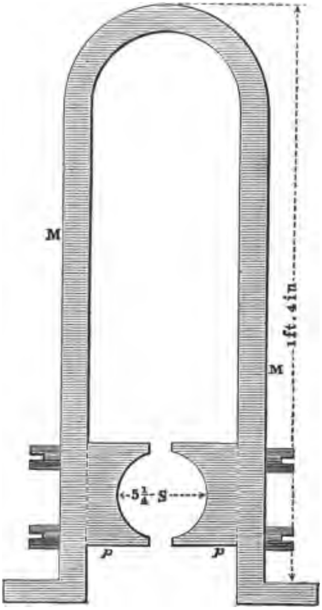


Fig. 36.—Small Gramme Magnet.

The bar should first be bent to a **U**-shape, with two limbs of equal length, and a space between them of 6¼ in. It may then be finished up, and have the screw holes for the cheeks and feet drilled. The screws may be ordinary ⅜-in. bolts or screws. The hardening and tempering should then be proceeded with. The bar should be hardened in a good charcoal fire, which must be of equal heat throughout the space occupied by the steel. As soon as a good blood-red heat is attained, plunge it into water, *bend first*, vertically. If this is not done as directed, it is probable that the bend will be softer than the other parts. The steel should be so hard that a file will scarcely cut it. Leave the "skin" on, and coat with sealingwax or other varnish, except where the cheeks, *p p*, are to bear. If the magnet is to be magnetised by rubbing with another, do not yet coat with varnish.

Magnetism may be obtained in two ways: these are, first, by rubbing with a sufficiently strong electro-magnet; second, by passing round the steel a strong current of electricity. Very few people possess electro-magnets of sufficient strength to impart much vitality to so large a mass of steel, so that it will be best in most cases to use the voltaic current. It will be necessary to place upon the steel legs a pair of long coils of stout cotton-covered wire. No. 16 B.W.G. wire will answer very well, and as many as four layers ought to be in each coil, if its length does not cover the straight part of the steel. The battery power to employ may consist of just as many quart Bunsens or bichromate cells over 6 as the maker may possess. The more battery power the more magnetism, usually up to 20 cells. Ten cells of the simple bichromate battery in series will answer very well. The current may be passed for about a minute, and the circuit should be broken several times during this minute. The bar will be more difficult to magnetise, as it is harder; but the magnetism will last longer without variation. The poles should be crossed by a piece of iron during magnetising. Care should be taken that the wire from one leg crosses to the other like the letter S; if this is not attended to, and the wire is not wound as it is upon common electro-magnets, the magnetisation will be a failure and must be repeated under different conditions. If the wire be coiled upon the steel direct, it will be safest for the amateur to continue the coiling over the bend, when the direction must be correct.

The cheeks *p p* are of cast-iron. They should be 6 inches high by 5 inches wide, and thick enough to allow of the 5½-inch circle, S, being cut from them. The space between their faces will thus be about half an inch or more. It will be best to have them cast to pattern, and then turned out. If there is convenience for annealing the cast-iron, this may be done in a charcoal fire by heating to redness and cooling slowly. The circular space, S, should be as true as possible, for it is upon the nearness of the iron to the ring that the effects, to a great extent, depend. The backs must be made flat, to bear truly upon the clean flat surface of the magnet itself.

If the base is to be of iron, and the feet of the magnet are to be secured to it direct, they must be of brass, and brass screws must be used. If a wooden base is to be employed, the feet and screws may be of any metal. It will thus be seen that care is necessary not to close the magnetic circuit of the horse-shoe by any iron prolongations. The magnetic arrangement must be made steadily fast to the base, in position, and the rest of the work may be proceeded with.

The Ring, or Armature.—In the Gramme machine the best form of ring consists of a flat bundle of soft iron wires, as is exhibited by Fig. 32, p. 75. The bundle of wires is a little more difficult to arrange in practice than one ring of iron. A good plan is to make it up of three 2-inch wide lengths of soft iron, one over the other. The innermost layer must be shorter than the second layer, and it must, in turn, be shorter than the outside layer. They are to form an almost complete ring, except a gap of 1½ inch wide, to allow the coils of wire, B, to be slipped on. This gap, when all the ring is coiled, is then to be filled up with a piece of iron having a coil of wire upon it. This will complete the ring, the iron body of which must be continuous. The diameter of the ring, *outside*, is to be 3½ inches, and its diameter inside will thus be about 2¾ inches, its width will be 2 inches, and this size of ring will, when coiled with wire, give an outside ring of 5 inches diameter or a little over, to fill the space S, Fig. 36, with clearance room.

The coils of wire, B B, Fig. 32, p. 75, are to consist of four layers of No. 16, silk- or cotton-covered. Silk will prove the better insulator, but cotton will answer, if well dried and soaked in melted solid paraffin. The layers of wire are to be 1½ inch or rather less in width. They should be first coiled upon a former or mandrel, having the same size as the ring body, and may be kept in shape by tying with silk thread and steeping in paraffin. They are to be slipped on, entering at the gap A A, Fig. 32,

p. 75, until the ring is quite full, and their ends, C C, are directed to one side. The last coil, filling up the gap in the ring, is to be placed upon the piece of iron filling up the gap. This iron piece should fit into the ends so as to *spring them apart*, and must have a catch or taper filed upon it to keep it in place when it is tightly pressed in. A ring made from a hoop of soft iron, solid, answers very well.

We have now the ring, with the wire upon it, and all the coil ends extending outwards at one side. There will be spaces at the outside not filled with wire, and they should be filled up completely with some such substance as melted pitch, to which some gutta-percha has been added. Concerning this, it should be remarked that these spaces will not exist if the contact plates of copper (D, Fig. 32) are placed *within* the ring, as there shown. It will, however, be easier for the amateur to leave the ends as they are, and to proceed to finish the ring as follows:—Turn a box or hard-wood drum to fit the centre of the ring tightly. Let it be *very slightly* tapered and somewhat rough, to give a hold to the cement. Its length should be 7 inches, and it should have a central aperture to receive a tightly-driven spindle of ½-inch round iron, of length over all 9 inches. Let the wooden drum pass through the ring until its thickest end is nearly flush with the wire coil, and the small end projects considerably. Mark this place, remove the ring, and in the wooden drum—commencing at the mark reached by the coils, make a number of slots or cuts with a saw. These cuts must be equal in number to the coils, and must radiate from the centre. Fig. 37 is intended to represent this. Now turn down the wooden drum for 2 inches at one end; reduce until the diameter is 1 inch; D, Fig. 37, will now represent this end so reduced. The depth of slots will be reduced also.

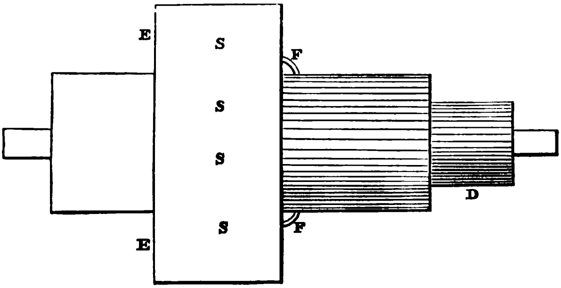


Fig. 37.—Gramme Ring and Contact Drum.

Into these slots must fit tightly pieces of thick sheet copper, D, Fig. 32, p. 75. These radiating slips must be driven in, and their edges should be flush with the wood drum, both at the wide and reduced parts.

File the slips down to the cylindrical form, connect the coils with the slips, and, to fasten on the ring, press the ring firmly on the spindle or drum. Melt a quantity of pitch and a little gutta-percha together, and fill in between the ring and the drum with it while very hot. When this sets it will fix the ring in position. Bring out all the cleaned extremities of the coils, and commence by soldering the finishing or outside end of No. 1 coil to No. 1 copper slip; solder also to No. 1 slip the inside or beginning end of No. 2 coil. Solder the finishing end of this coil to No. 2 slip, and to the same slip the commencing or inside end of No. 3 coil. Continue thus until all the coils are connected to the copper slips, paint over with hot gutta-percha and pitch, and the ring with its connections is complete.

Fig. 37 will render the arrangement more clear, where E E represents the ring upon its axis, S S the coils, F F the ends of these joined to the copper slips, which lead along the drum, as the lines indicate, to D, which is the reduced end spoken of, with the slips having their edges flush with it.

Fig. 33, p. 77, will render the whole still more intelligible; but there are joints shown here which are intended to represent the way in which Gramme mounts the ring upon its spindle.

The actual construction of the spindle and the mounting are ordinary mechanical operations. The toothed driving-wheel may conveniently have a diameter of 10 inches, and the pinion a diameter of 1½ inches. The number of teeth is a matter of little consequence, but the pinion and wheel must agree as to *pitch* of the teeth, otherwise they will not run together.

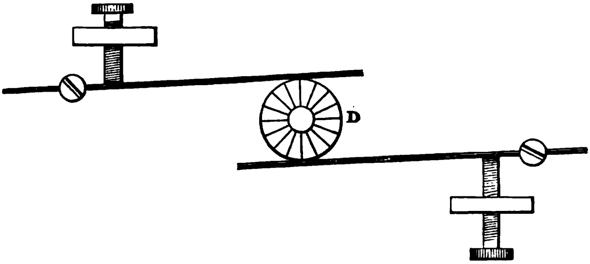


Fig. 38.—Contact Springs and Drum.

It will be found best to provide a gun-metal pinion, and to drive a pin right through its hub and the spindle. The height of the standards must be regulated accurately, to allow the 5-inch ring to revolve freely in the space S, Fig. 36. Nothing further should be done until this part is very exactly fixed in position. The distance between the centres of both spindles must be marked off on the uprights, and will always afterwards be correct. The lower spindle must be so set that the ring occupies as nearly as possible the central portion of the cheeks *p p*, Fig. 36.

As to the side of the machine at which the reduced or "contact" end of the wood drum projects, it is of little consequence; but it will be found most convenient to project it from the side opposite to the driving-wheel, because arrangements are to be fixed here for carrying a pair of contact springs for collecting the current from the copper slips, as they project at D, Fig. 37.

When the ring is caused to revolve without the contact brushes pressing upon the slips, there can be no circuit for currents, so that no currents are induced in the ring by the magnet.

Reference to Fig. 38 will render clear the manner in which the contact springs should be arranged. One presses upon the upper side of the drum end, and the other on the under side of the drum. The edges of the radiating slips being flush with the circumference, there is not a heavy contact, but it is sufficient to collect the impulses as they are given off. These currents are constantly in one direction, and in this respect resemble a fall of water.

The springs represented at Fig. 38 are most conveniently made up from a number of stiff copper wires; but brass wires will answer, although they will be burned sooner if there is much sparking. The springs should be adjustable, through the screws fastening them, to expose fresh surface to the friction when necessary; and the thumb-screws shown serve to cause them to bear more or less heavily upon the axis. This part must be oiled occasionally.

From these contact springs the wires are taken to the binding-screw exhibited in Fig. 34. Stout covered wires should be employed to connect the machine to any piece of apparatus. M. Breguet supplies with the machine two rings, with thick and fine wire, for currents of low and high electro-motive forces. The currents must always be collected upon or near the neutral line.

De Meritens' Machine.

The construction of this machine provides for the armature a wheel, with a rim composed of segments of soft iron, wound as usual with wire at right angles to the iron segments, which are separated magnetically by strips of copper. All the segments are wound in one direction, but the outside end of one coil is joined to the outside end of the next, and the inside end is joined to the inside of the preceding coil.

This ring-tire armature is made to revolve inside the poles of a number of permanent steel magnets, arranged around in a circle parallel to the shaft of the revolving wheel. There is thus a regular succession of poles in the ring—N.S.N.S.

By this arrangement of coils, and the size of the coils in relation to the distance between the magnets, as one coil is approaching a north pole the next is approaching a south pole. Currents in *opposite* directions in these two *coils* are therefore produced, but by the mode of coupling the ends of the coils described above, these currents become in the *circuit* in the *same* direction. The current, however, is of course reversed as any one magnet approaches and then recedes from any one pole, thus the machine produces currents which alternate in their direction.

The terminations of the wheel coils are soldered to a pair of brass or copper rings upon, and insulated from, the central spindle. From these rings the current is taken off by copper brushes, usually composed of springy wire of large size.

It has been found that this machine produces remarkably strong currents in comparison with other machines of the same type. Were the sections composing the circular armature not insulated magnetically from each other as they are, some comparison might be made with the Gramme magneto machine, for the currents are induced under similar conditions, except that De Meritens employs a number of small magnets.

CHAPTER V.

ELECTRO-MAGNETO ELECTRIC MACHINES.

HITHERTO we have only alluded to magneto-electric machines in which the current was produced by revolving coils of wire placed on soft iron cores, near fixed permanent magnets, or *vice versá*, revolving permanent magnets near fixed coils. It will be evident, however, that electro-magnets excited by currents from some source of electricity may be substituted for fixed permanent magnets; and, in fact, in 1845, Professor Wheatstone patented the substitution of electro-magnets for permanent magnets in magneto-electric machines for telegraphic purposes, and in 1852 Watt, in a patent, mentions the same idea; but no particular use seems to have been made of these suggestions.

Wilde's First Machine.

In 1863 Mr. H. Wilde, of Manchester, took out a patent for a machine for obtaining electric currents in which a large electro-magnet was excited by means of a battery, or by the current from the armature of a small magneto-electric machine, both machines having Siemens' armatures, a commutator being arranged on the small machine, so as to give a current in one direction round the electro-magnet of the large machine. Mr. H. Wilde constructed a large machine on this principle, and appears to have first brought the principle before the public in two papers, read at the Royal Society on April 26th, 1866. "1. On some new and paradoxical phenomena in electro-magnetic induction, and their relation to the principle of Conservation of Physical force. 2. On a new and powerful Generator of Dynamic Electricity."

The machine described consisted of a small magneto-electric machine, in which the magnets were permanent magnets, and the armature a Siemens' armature, standing on a large magneto machine, in which the magnets were electro-magnets, these electro-magnets being excited by the current from the armature of the smaller machine. The current from the large armature was consequently very powerful.

Fig. 39 shows an end elevation of this machine. M M′ is the small permanent magneto machine with its Siemens' armature C; *r* and *r′* are the terminals connecting the commutator brushes of the small machine to the insulated copper bands of the large electro-magnet E E.′ The wires Z and Z′ show the external circuit connected to the contact brushes of the armature of the large electro-magnet.

Mr. Wilde carried his principle further, and made and described a machine where the current from the first excited the electro-magnets of a second, and the current from the second excited the electro-magnets of a third, the diameters of the Siemens' armatures being respectively 1⅝ inches, 5 inches, and 10 inches.

The magnets of the small magneto-electric machine consist of six magnets weighing 1 lb. each, and the magnets of the 10-inch machine weighed 3 tons. The machine was furnished with two armatures, one for the production of "intensity," and the other for the production of "quantity," effects.

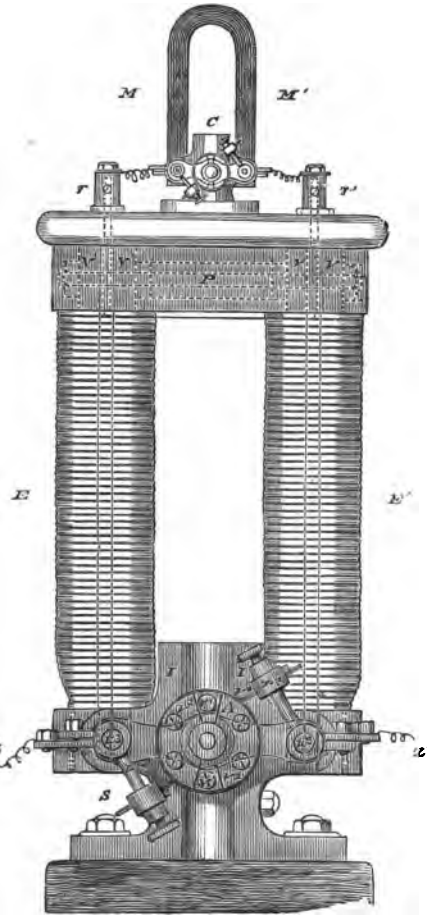


Fig. 39.—Wilde's Magneto-Electric Machine.

The intensity armature was coiled with a bundle of thirteen No. 11 copper wires 376 feet in length, and weighing 232 lbs.

The quantity armature was wound with copper plate 67 feet long, weighing 344 lbs.

The armatures were driven at the rate of 1,500 revolutions per minute.

When the large machine was excited by the medium, which in its turn was excited by the smallest machine, enormous effects were produced, and a piece of iron 15 inches in length, and ¼ of an inch in diameter, was melted. This was with the quantity armature. With the intensity armature the current produced melted 7 feet of No. 16 iron, and made a length of 21 feet red-hot. The intensity armature was used for the electric light, with gas carbon ½ inch square, and the light evolved was sufficient to cast a shadow from the flames from the street lamps a quarter of a mile distant.

In March, 1867, Mr. Wilde exhibited a large machine of this description at the conversazione of the Royal Society at Burlington House. The electric light was shown in great splendour, and iron rods of the above dimensions were fused.

Wilde's Armature.—Although the distinctive features of Wilde's machine lie in its magnets and arrangement, the make of Siemens' armature adopted by him calls for further explanation.

Fig. 40 exhibits this construction. The metallic portion of the armature is shown in the end view with cross section lines and the wire wound upon it in three layers. This cast-iron body extends from A to A, and in its longitudinal side grooves the wire is wound. The length of covered copper wire wound is about

50 feet, and after the wire is on, a wooden packing serves to keep it in place and make up the circular form of the armature. Straps of brass encircle the armature at different intervals along its length; this prevents the coils from being forced outwards by centrifugal force. These are sunk in grooves made for them in the cast-iron body and wooden packing E. Two ends of brass are fitted to the ends of the armature, and to these brass caps are made fast the steel axis ends C C. D is the pully by which motion is given to the armature from a strap.

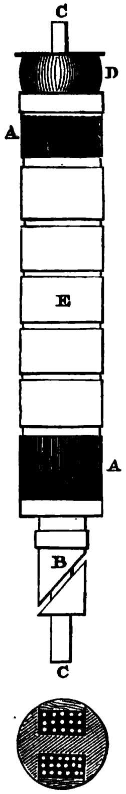


Fig. 40.—Wilde's Armature.

The Commutator is of simple construction, and is shown at B. It is composed of two rings or sections of copper, fitted upon the steel shaft C, and insulated from each other. Upon this commutator or current-reverser press the contact springs which take off the currents. One-half of the commutator is connected to the commencing end of the coil, and the other to the finishing end. As soon as the armature begins to move, a current begins to be induced in it, and for each revolution two opposed currents are given rise to in its coil. If the springs press upon the commutator, it will be seen, since the latter is separated by an oblique cut, that the springs must exchange parts at each half revolution, and as this exchange takes place at the moment when the armature reverses its current, the springs take off the current in one continuous direction.

CHAPTER VI.

DYNAMO-ELECTRIC MACHINES.

THE machine made by Mr. Wilde was an immense step in advance of all previous means of obtaining electricity from motive power, but a further step was very shortly to be made of still greater importance.

About the end of 1866, or beginning of 1867, the idea of employing the current, or a *portion* of the current,* from an electro-magnetic electric machine to *excite the electro-magnets* themselves, thus dispensing with voltaic batteries or any primary exciting machine, occurred to Messrs. Varley, Siemens, and Wheatstone. Messrs. Alfred and Cornelius Varley patented this principle in 1866. In January, 1867, Dr. Werner Siemens communicated this principle to the Academy of Science at Berlin, and in February, 1867, Dr. W. Siemens communicated the same to the Royal Society. About the same time Professor Wheatstone published a similar idea. But all these gentlemen were, as far as printed publication went, long anticipated by Sören Hjorth, of Copenhagen, who in 1848 had patented this principle very distinctly, giving drawings in his specifications. *Specification of Patent* 12,295, 1848.

Mr. Murray also, in the *Engineer* of July 20, 1866, states that he, using only a single machine, passes the currents from its armatures through wires coiled

---

* Constituting what is now well known as a SHUNT WOUND dynamo.

round the permanent magnets in such a direction as to intensify their magnetism, which in its turn reacts upon the armatures and intensifies the current.

On February 14, 1867, two papers on this subject were read before the Royal Society. The first, received February 4, was "On the conversion of Dynamical into Electrical Force without the aid of Permanent Magnetism," by C. W. Siemens, F.R.S.

The author says, "An experiment has been suggested to me by my brother, Dr. Werner Siemens, of Berlin, which proves that permanent magnetism is not requisite in order to convert *mechanical* into *electrical* force; and the result obtained by this experiment is remarkable, not only because it demonstrates this hitherto unrecognised fact, but also because it provides a simple means of producing very powerful electrical effect." After describing the principle of a dynamo machine, in which a single element of a battery was used to start the magnetism, he says, "The co-operation of the battery is only necessary for a moment of time after rotation has commenced, in order to introduce the magnetic action which will thereupon continue to accumulate without its aid. The mechanical arrangement best suited for the production of these currents is that originally proposed by Dr. Werner Siemens in 1857 (see 'Du Moncel sur l'Electricité,' 1862, page 248), consisting of a cylindrical keeper hollowed at two sides for the reception of insulated wire wound longitudinally, which is made to rotate between the poles of a series of permanent magnets, which latter are at present replaced by electro-magnets.* On imparting rotation

---

* It being understood that the current from the armature is by suitable commutator led round the electro-magnet coils.

to the armature of such an arrangement, the mechanical resistance is found to increase rapidly to such an extent that either the driving strap commences to slip, or the insulated wires constituting the coils are heated to the extent of igniting their insulating silk covering.

"It is thus possible to produce mechanically the most powerful electrical or calorific effects without the aid of steel magnets."

The second paper, received February 14, was "On the Augmentation of the Power of a Magnet by the reaction thereon of currents induced by the Magnet itself," by Charles Wheatstone, F.R.S.

The author states,* "In the present note I intend to show that an electro-magnet, if it possesses at the commencement the slightest polarity, may become a powerful magnet by the gradually augmenting currents which itself originates." He then describes a machine the same as the electro-magnetic part of Mr. Wilde's machine, and then goes on to show that little effect is produced by temporarily exciting the electro-magnet if the circuits of the armature and magnet are separate. But if the wires of the two circuits (*i.e.* the electro-magnet and armature coils) be so joined as to form a single circuit, in which the currents generated by the armature, after being changed to the same direction, act so as to increase the existing polarity of the electro-magnet, very different results will be obtained. The force required to move the machine will be far greater, showing a great increase of magnetic power in the horse-shoe; and the existence of an energetic current in the wire is shown by its action on a galvanometer, by its heating 4 inches of platinum

---

* Proceedings of the Royal Society.

wire ·0067 in. diameter, by its making a powerful electro-magnet, by its decomposing water and other tests.

The principle thus brought prominently forward by Dr. Siemens and Professor Wheatstone, and previously patented by Sören Hjorth and Messrs. Alfred and Cornelius Varley, and published by Murray, was soon brought to bear in the construction of an infinite variety of machines for obtaining electricity from mechanical motion without the aid of permanent magnets or batteries, and the name of dynamo-electric machine has been given to them in distinction from magneto-electric machines, where permanent magnets are employed. Dr. Siemens' machine, constructed to show the principle, consisted of flat electro-magnets like Wilde's, with the Siemens' armature, only the machine was laid horizontal instead of vertical.

Mr. Wilde soon adapted this principle of reaction to his machines, dispensing with the permanent magnets, but still using a small electro-magneto electric machine, as well as a large one, the current from the armature of the small machine being made to pass round the wire of both machines to excite their electro-magnets. The current from the armature of the large electro-magnets was used alone for external purposes.

As the heat is sometimes great, some of Wilde's machines have the central shaft hollow, and a current of cold water is caused to pass through it, and also through the tubular large electro-magnet.

These machines have had their chief application in electro-metallurgy, but they have also been used for the production of the electric light.

Ladd's Dynamo-Electric Machines.

Mr. Ladd, of London, made a machine, Fig. 41, which differed from Wilde's in having two flat electro-magnets, B, placed parallel, with Siemens' armatures, C C, revolving at each end of the system. The current from one of the armatures excited the electro-magnets, and the current from the other was used for external purposes. Mr. Ladd also constructed the form of machine exhibited in Fig. 42, with two armatures fastened upon one shaft; one armature is used to excite the electro-magnet and the other is reserved for outside work.

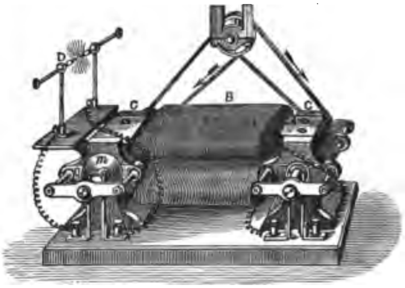


Fig. 41.—First Form of Ladd's Machine.

Holmes' Dynamo-Electric Machine.

In 1869 Professor Holmes made a dynamo-electric machine for the Trinity House. The machine consisted of ten electro-magnets fixed to a revolving shaft, the poles of the magnets, turned outwards from the shaft, passing as the shaft revolved by fixed coils. A part of the current from the coils was passed along the shaft to the coils of the electro-magnet. It was intended for use in the South Foreland, and gave 2,800 candle-power, but was not put into operation.

From this point we do not pretend to give descriptions of the various machines in the order of the date of their invention.

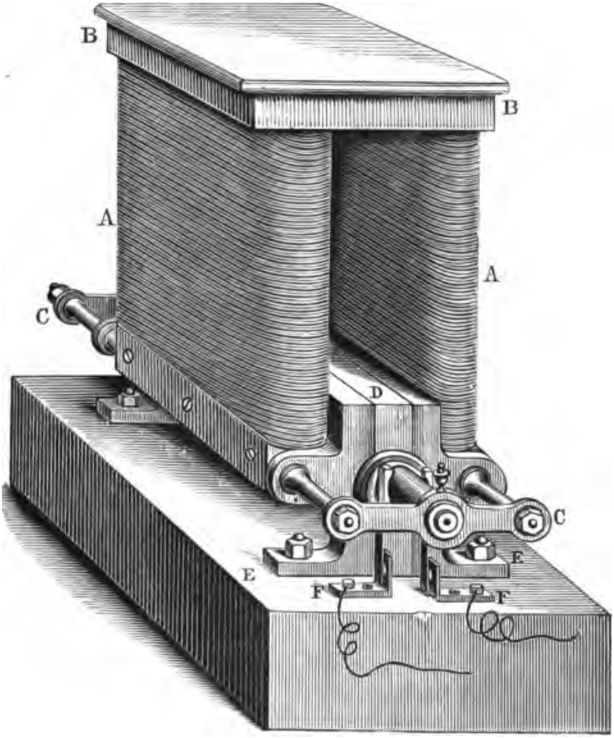


Fig. 42.—Ladd's Machine.

Gramme's Dynamo-Electric Machine.

The Gramme magneto-electric machine has been described; the Gramme ring armature being the essential feature of the arrangement. In the Gramme dynamo-electric machine the ring is the same in principle and form, but the magnets are electro-magnets, formed by bars magnetically joined by the frame of the machine, and the insulated wire on them is wound in such a way that the mass of metal joined to the *centres of the bars*, or groups of bars, are the *magnetic poles* when the magnets are excited. The current from the coil is led through the electro-magnet coils as in most dynamo-electric machines.

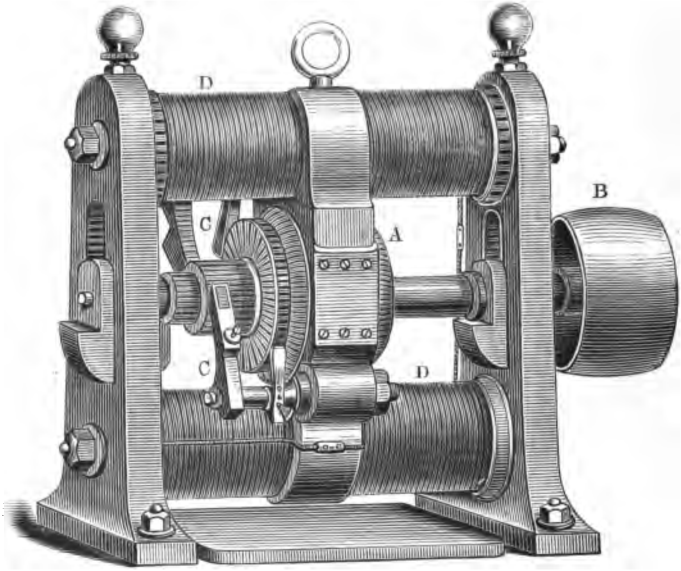


Fig. 43.—Small Gramme Machine.

Fig. 43 is a view of a complete Gramme machine of the smaller type. It is much used in electro-plating and in illuminating workshops. The illuminating power of the current it yields is about 2,000 candles.

Its weight is 1 cwt. 2 qrs. The armature should make 1,600 revolutions per minute, with an expenditure of 1½ H. P.

D D are electro-magnets, connected through the framework, and this brings the poles to the cast-iron cheeks which embrace the ring above and below. The system composes, therefore, one electro-magnet.

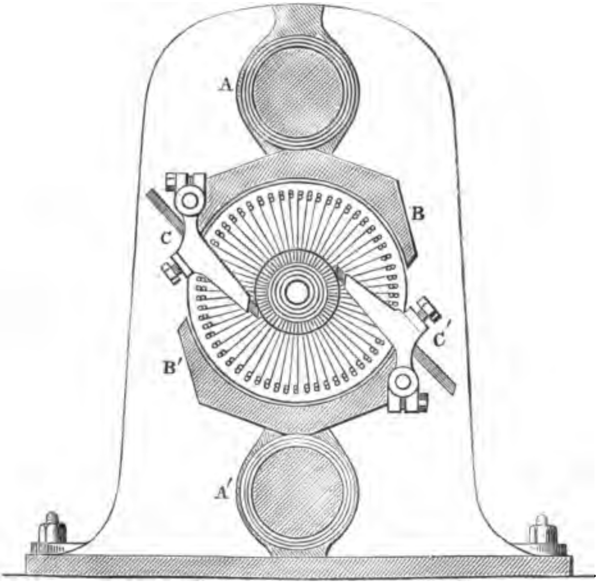


Fig. 44.—Gramme Machine: Section.

A is the ring, C C the collecting brushes, B the driving pulley. The height of this machine, as shown, is 23 inches. Length 25 inches, width 13 inches.

Fig. 44 is an end sectional view of a Gramme machine of a small size. A A′ are bars of the electro-magnets, wound with thick copper wire. These bars form the two poles of a magnet, as they are connected together at their ends, through the framework of the machine. B B′ are the pole pieces, or cheeks, which embrace the ring for about seven-eighths of its circumference. The ring revolves very near to them. C C′ are the collecting pads, brushes, or springs. These usually consist of a bundle of hard copper slips, or hard copper wires, passed through, secured by, and regulated as to length through the holders shown. These brushes need attention about once a day, when the machine is in constant action. They must not press heavily upon the axis, but the pressure should be increased until most of the sparking is taken up. These sparks, given off by slight breaks in the circuit, soon burn the brushes and contact pieces.

Gramme's machines of this type are now made in several sizes, to give from 2,000 to 16,000 candle-lights, with horse-power required of from 1½ to 6, and in weight from 1 to 8 cwts.

Fig. 45 illustrates one of the large machines constructed by Gramme, for the production of large currents. It has 6 bar magnets, 2 rings, and weighs 1,540 lbs. The copper wire upon all the magnet bars weighs 400 lbs., and upon the ring 80 lbs. It is found to give an electric light of about 4,000 candles, but is not so well adapted for electric illumination on the arc principle as for the working of incandescent lamps.

Two of Gramme's 16,000 candle-power machines were employed to burn the electric candles on the Thames Embankment in the early experiments in London in 1878-80. One of these machines burns 20 "candles." The connections in the ring of this larger machine are not made all on one side. There are 120 radiating slips, 60 on each side of the ring. These lead to two collecting cylinders, and four collecting pads press upon the cylinders to take up the currents.

Work of the Gramme.—In a communication to the Academy of Sciences, M. Tresca gives an account of a series of experiments which he had instituted for the purpose of determining the work performed by the dynamo-electric machines of M. Gramme. His experiments had reference to two machines emitting

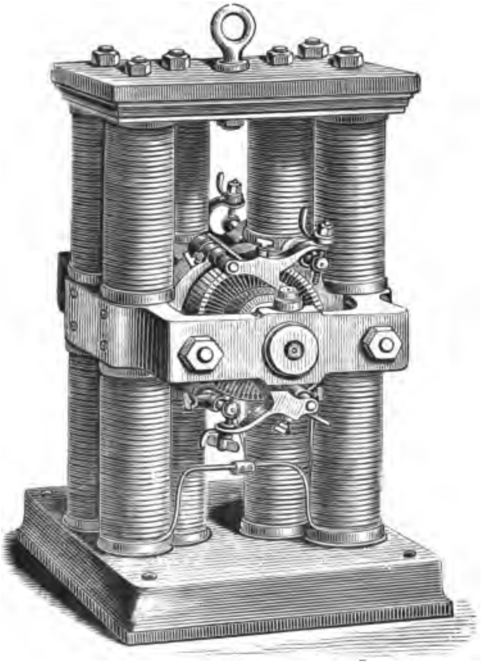


Fig. 45.—Large Gramme Machine.

light equivalent to 1,850 and 300 Carcel lamps respectively.*

A similar series of experiments were carried out at the French Northern Railway depôt, with Gramme machines of 50, 100, and 150 Carcel lamp power respectively. The power necessary to drive the machine was ascertained by a comparison with engines driven by gas or steam, of 2, 3, or 4 horse-power, used either separately or coupled. Previous determinations, carefully ascertained, however, with a Prony dynamometer, had given the relative volume of gas consumed to the power derived (*i.e.* useful work), all the conditions remaining the same.

The lamps employed in the experiments were of the Serrin type, and answered the purpose remarkably well. The following results were obtained. The horse-power is given in Force de Cheval = 0·9876 of a horse-power.

	Dynamo-Electric Machine of		
	50-Lamp Power.	100-Lamp Power.	150-Lamp Power.
Number of revolutions of bobbin per minute	1,650	800	800
Power necessary to secure a steady light—			
With carbons 0·007 m. apart	2·2 ch.	2·4 ch.	2·5 ch.
Ditto 0·009 m. apart	,,	2·6 ch.	2·7 ch.
Consumption of carbons, including waste—			
With carbons 0·007 m. apart—			
At positive pole	2·2 ch.	0·090 m.	0·135 m.
Ditto at negative pole	,,	0·045 m.	
With carbons 0·009 m. apart—			
At positive pole	,,	0·060 m.	0·090 m.
Ditto at negative pole	,,	0·030 m.	

The following figures will be of interest as exhibiting the comparative cost of electric lights and

---

* The Carcel lamp is a standard in France, consuming 648 grains of pure oil per hour. Its value in English standard candles is about 13, or, roughly, it is equal to a gas-jet consuming 4 cubic feet per hour.

gas, as ascertained through the experiments undertaken by the Northern Railway Company of France.

Taking, for example, the lamp of 150 Carcel lamps, and allowing it to emit light for 10 consecutive hours in some spacious hall or railway depôt, 150 Carcel lamps will require a consumption of 150 × 1·105 mc. of gas per hour, equal to 15·75 m., which, at the rate of 0·36 fr. per cubic mètre, would constitute an expense of 5·70 frs. In the use of electricity for the illumination, 150 Carcel lamps require 2·7 ch., which, at the rate of 0·09 fr. per horse-power per hour, including cleaning and lubrication, the expense would amount to 0·24 fr. Adding to this 0·09 fr. for carbons, 0·45 fr. for wages to the employé, and 0·20 fr. for the interest and liquidation of the expense of instalment, the total amount would be 0·98 fr., or, in other words, between one-fiftieth and one-sixtieth of the expense involved when using gas for the illumination.

An electric light of 150 Carcel lamps lights up advantageously a circle of about fifty mètres in diameter, and it is evident the illumination by electricity, being so much superior in intensity, ought to be more economical than gas, since the illumination of the *same area* requires the light of more than twenty-five gas jets, consuming 105 litres per hour.

The best make of Gramme machine now produced, of the 6,000-candle type, is, length, 1 ft. 11 in.; breadth, 1 ft. 3 in.; height, 1 ft. 8 in.; weight, 3 cwt. 1 qr. 22 lb.; horse-power absorbed, 2·5; revolutions per minute, 850; light in standard candles, condensed beam, 6,400; diffused beam, 4,000; *light produced per horse-power*, in standard candles, condensed beam, 2,560; diffused beam, 1,600.

The following are a few further particulars of these machines.

Class.	Light in Standard Candles.	Horse-power required.	Revolutions per Minute.	Weight.	Extreme Dimensions.					
					Length.		Breadth.		Height.	
				cwts.	ft.	in.	ft.	in.	ft.	in.
O	800	½	1,600	1½	1	6	1	2	1	4
M	2,000	1½	1,600	1½	1	6	1	2	1	4
A	6,000	2½	900	3¾	2	4	1	4	1	11
C	†15,000	5	700	8	2	5	1	10	2	2
	*25,000	8	1,200							
D	†25,000	8	300	20	3	2	2	8	2	8
	*45,000	13	500							

† Tension. * Quantity.

The intensity of light here quoted is approximately that given by a machine working with a Serrin lamp in good order. When other lamps are used, the intensity of light may differ from the above results. The figures are given as a guide only.

Gramme's Distributor Machine.

For the Jablochkoff candle, consisting of two carbons placed parallel and insulated from one another, which will be described further on, alternate currents are required, and for this purpose, and for producing currents in several separate circuits M. Gramme devised a machine called the "distributor," which is used in conjunction with an ordinary Gramme machine.

The machine in external appearance resembles a wooden drum fixed by feet and bolts to a firm base.

Directly inside the drum surface is a flat ring of iron, divided into 8 sections, and half of each section is coiled alternately right and left with covered wire. The whole outside system is therefore simply 8 flat curved electro-magnets. Within this circle, projecting from the axis of the machine like the spokes of a wheel, are 8 wide and flat electro-magnets, which are also wound with wire alternately right and left, their exterior poles being thus alternately north and south. This central system is caused to rotate, and into the coils of the magnets is passed the current from an ordinary Gramme generator. There is no actual connection between the revolving system and the outer 8-section ring. The electro-magnets act as usual by induction upon it, and cause each section to give alternate currents. These sections may be subdivided again into right and left subsections. The subsections may also be wound in one direction as in the Gramme ring. The wires of the central rotating electro-magnets form one continuous circuit, and the current is simply passed into it by a pair of copper wire brushes pressing upon two copper rings connected to the extremities of the circuit. The speed is from 300 to 600 revolutions per minute, with horse-power of from 10 to 16, and it is usual to drive both generators and distributors from one engine.

These machines are constructed to provide from one current several separate currents, each capable of maintaining one or more electric candles in action.

Taking two notable examples of the application of this machine, it was the one used to distribute the main currents to Jablochkoff's candles as employed lately in Paris. It was the machine in use in the illumination of the Thames Embankment. In this latter instance of electric illumination, the main generators (of which there were two) were 16,000-candle power Grammes; the current from these was passed into the distributing machines, which sent alternate currents into 4 circuits, in each of which there were 5 candles.

Gramme's Combined Exciting and Dividing Machine.

This is a more recent form of the Gramme apparatus. In it the exciting ring and "distributing" or "dividing" coils are combined and form one machine. Figs. 46, 47, 48, and 49 represent this apparatus.

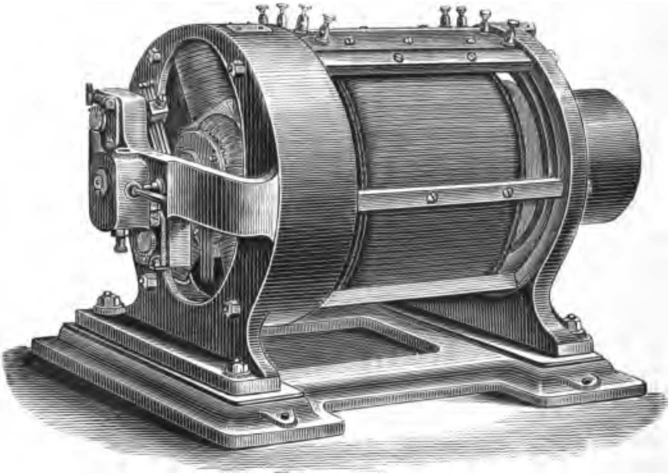


Fig. 46.—Gramme's Combined Machine.

The machine, a general view of which is given in Fig. 46, is arranged as follows: On a cast-iron foundation are fixed two plates of the same metal, almost circular in shape, forming the standards upon which the electrical parts are mounted. They are connected together by six square bolts, and are provided with bearings for the main shaft (see longitudinal section shown in Fig. 47). One of these plates is furnished on the inner side with a circular rib, on which are mounted the electro-magnets for exciting the ring, as shown by the cross section Fig. 48. As in the model previously described, the coil for the alternating currents rests on the square bolts connecting the end plates of the frame with packing pieces of hard wood. One end of the frame thus carries the electro-magnets of the exciter, while the central portion supports in position the large flat coils of the distributor, shown in cross section in Fig. 49. Upon the main shaft is mounted, at one end, the exciting coil, which revolves between the poles of the fixed electro-magnet (see Fig. 48). The central portion of the main shaft carries a hexagonal sleeve, upon which are bolted the six electro-magnets of the large distributing coil, shown in cross section in Fig. 49. The shaft thus carries at one end the exciting coil, and upon its central portion the six electro-magnets, radially arranged, which induce the currents in the distributing coils (see Fig. 47). Wide bearings are employed, and in the

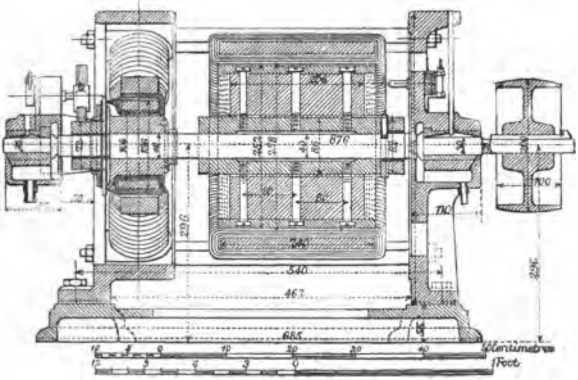
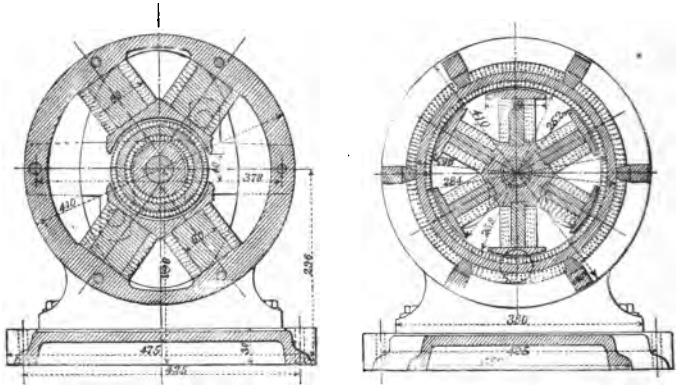


Fig. 47.—Gramme's Combined Machine.

larger machines a system of automatic lubrication is in use.

An arm carrying a wire brush, shown in the longitudinal section, Fig. 47, serves to place in communication the coils of the moving electro-magnets with the exciting ring. The current is collected and transmitted by small brushes of silvered copper wire. The brushes are worked by means of a small endless screw. For regulating the power of the machine, a copper wire, the length of which can be varied at will,



Figs. 48 and 49.—Gramme's Combined Machine.

is introduced between the exciter and the electro-magnets. The method of coiling the wire differs slightly from that adopted in the other machines, as, instead of winding only one wire, two are coiled, in order to obtain by this mode of coupling high E. M. F. currents for small lights, or low E. M. F. currents for large lights. Two types of this machine are now manufactured. The smaller weighs 616 lbs., and supplies 12 candles of from 20 to 30 Carcel burners, or 8 candles of from 40 to 50 Carcel burners. The larger machine weighs 990 lbs., and furnishes power of 24 candles of 20 to 30 Carcel burners, or 16 of 40 to 50. The following table contains the results of some experiments with these machines:—

Number of revolutions per minute.	Horse-power expended.	Number of lamps.	Power of each light in Carcel burners.
1400	5	12	28·5
1425	6	8	43·0
1200	4	6	48·5
1000	13	16	48·0
1020	13	16	51·3
1200	14	24	31·0

With a machine specially arranged for small lights, there have been obtained, with a speed of 1,250 revolutions, 14 lights of 20 Carcel burners each with an expenditure of 4·66 horse-power. The candles employed had carbons 3 mm. (·12 in.) in diameter. In all the experiments made a much steadier light was obtained than that given by the machines employing an independent exciter.

Drum Armatures.

The first useful armature of this type appears to have been that introduced by Alteneck in 1872, and embodied in the Siemens' machines of this kind. This invention marked a great advance in the construction of dynamo machines. The drum form presents many advantages considered electrically, but is mechanically difficult to construct and keep in repair. On the whole, for dynamos of moderate size, the drum form, notwithstanding its disadvantages when compared to ring and disc armatures, is by far the most suitable.

The drum form of armature, having been used in so many makes of machines, will form a useful example for particular description. In many machines the exact course of the winding adopted may vary somewhat from that introduced in the Siemens' machines, and in many cases these deviations from the invention of Alteneck may have their advantages, but broadly speaking the winding of this inventor's armature will convey to the mind a very clear idea of the general methods adopted by others.

Cores.—The cores of drum armatures are variously constructed. The chief object to be aimed at is the elimination of self-induction, or eddy currents in the iron, and the arrangement of the parts so as to secure circulation of the air and consequent coolness of the whole structure.

These ends are not so easily accomplished as would at first sight appear.

A solid cylinder of hard iron would present an example of the worst possible kind of core. A mere shell of the softest iron, built up of many layers or sections, magnetically insulated from each other, has been found by far the best arrangement.

A very much used method of forming the core consists in building it up from a very large number of soft iron discs or stampings, bound together (after the appearance of a pile of coins), so forming a cylinder. The stampings are variously ventilated by being provided with apertures of different shapes, forming channels longitudinally of the armature.

Again, the stampings, or discs, are variously formed after the manner of a toothed wheel having few teeth. When bound together this method produces a cylindrical core having longitudinal channels, in which the wire coils may be buried—indeed this is a favourite method. In any case the discs are usually insulated from the central shaft. A common device for binding the whole together once consisted of three or more bolts passing from end to end of the core through apertures and secured with nuts. This was found to diminish the output of the armature and to increase its heating tendencies by the production of useless currents.

A later and improved arrangement consists of end washers and screw threads, with lock-nuts cut upon the axis itself.

In some of the best machines yet constructed the core consists chiefly of iron wire, after the manner of Gramme, in forming the annular armature. A well tested method consists in fixing upon the shaft a pair of gun-metal cheeks or flanges to form the extremities of the cylinder. Upon these is placed a cylinder of thin sheet-iron, leaving the body of the armature hollow, and upon the iron shell is wound compactly several layers of soft iron wire.

Winding.—The methods of winding now in vogue are vastly more numerous than the arrangements of the core, and it will only be practicable to cite one or two leading examples.

One of the best known schemes for disposing of the wire is that adopted by Alteneck.

Let us suppose a cylindrical armature, having a commutator upon its axis. One extremity of the wire to form a coil or section is attached to No. 1 bar of the commutator. The wire is then led along parallel to the axis of the armature, across its further end (passing to one side of the shaft) and back again along the opposite diameter of the armature, the finishing end being attached to No. 2 bar of the commutator. Several turns of the wire are, of course in practice, made so as to form a coil of several turns (usually eight) before the end is brought to the commutator in the manner described. In this method of winding several convolutions the wire is usually passed to the right and left alternately of the shaft at either end, so as to equalise space occupied. A second coil is begun at No. 2 bar, and finishes at No. 3 bar, and so on. One half of a coil is thus passing through N magnetic field while the corresponding half is traversing S magnetic field. But in practice, say for an armature having twelve sections, the second coil to be wound is No. 6, so that diametrically opposite numbers overlap each other. Thus, while No. 6 overlaps No. 1, No. 7 will overlap No. 2. This precaution is taken to prevent "sparking" or breaking down of the insulation, by separating those sections having greatest difference of potential.

In the earlier forms of the drum armature the windings were arranged as in Fig. 51.

The form of conductors with which drum armatures are wound is not always wire. Copper ribbon and wire of square section are in general use, the former for machines of low resistance and the latter for saving space in the winding. But many drum armatures are surrounded, not by an envelope of wires but by a series of copper bars, as in Edison's machines, the object being to reduce the armature resistance to the lowest possible point. When bars are employed it is very usual to form the cross or end connections by means of a series of copper discs, concentric with the axis.

To a limited extent the effect of reducing the electrical resistance of the armature can be obtained by different methods of grouping the coil sections, and this is frequently done, in the case of machines for electro-metallurgy especially.

The usual conception of a drum armature places it between a pair of opposed external magnetic poles, but the idea of making the armature a fixture and of causing the field magnet to revolve within it has been suggested by M. Cabanellos, and has, in several lately constructed machines, proved a most advantageous form of construction. The armature may, of course, revolve while the field magnet remains fixed.

Iron cores generally form part of drum armatures, but are by no means an essential constituent of this type. Powerful armatures have been constructed of non-magnetic material, such as a core of wood, and have the great advantage of keeping coöl at high velocities. There can be no doubt, however, that the use of iron greatly augments the power of the currents, and enables a small machine to exhibit results greatly exceeding those obtained from armatures formed of conductors only.

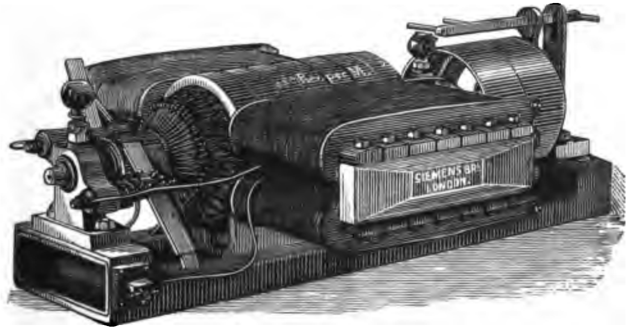


Fig. 50.—Siemens' Continuous Current Dynamo Machine.

Siemens' Machines.

Continuous Current Machines.—The usual form of the Siemens' smaller machines for the production of continuous currents is represented in Figs. 50, 52, and 53. The distinctive feature of the machine lies in the armature, which is a development of the original shuttle form of armature introduced by Dr. Siemens, and represented in connection with the Wilde machine.

Siemens' improved armature consists of a hollow soft iron cylinder, mounted upon an axis in the direction of its length. Every portion of the exterior surface of this cylinder, including its ends, is covered by a wire envelope several layers deep. The wire is arranged in sections, and connected together so as to throw the active sections into the circuit at the right moment, or at the instant when they become active, by cutting the magnetic field. The wire is wound on the armature in a peculiar manner of grouping invented by Häfner von Alteneck. Each convolution is parallel to the axis of the cylinder, and the wire is arranged in 6 sections of two coils each, having 24 extremities, which are connected up so that two of those ends are connected to each of the segments of a circular commutator having 12 divisions. The arrangement of the sections of the wire envelope may be better understood by reference to Fig. 51, which represents the commutator end of the armature. N and S represent the poles of the field-magnet, situated in this machine upon a vertical line passing through the axis of the armature. The central portion of the diagram is intended to show the arrangement of the extremities of the wire coils. C C, etc., are a series

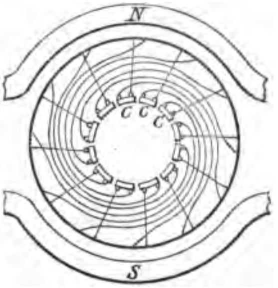


Fig. 51.—Diagram of Connections in Siemens' earlier modified armature.

of 12 copper plates arranged upon and parallel to the axis of an insulating cylinder called the commutator. Each plate is furnished with two connecting screws to receive the wires. The sections are so connected to the plate that, while the commencing end of No. 1 section is attached to No. 1 commutator plate, the finishing end of the same section is carried round to the plate diametrically opposite, as represented. The same arrangement is carried out with the other sections. It is difficult, however, to represent the arrangement of the wires in this armature by diagrams or written description.

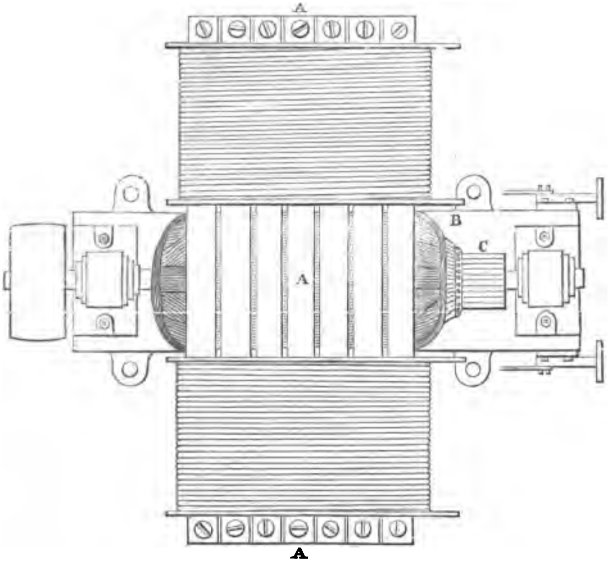


Fig. 52.—Siemens' Machine.

The machine itself, the horizontal form of which is represented in Fig. 50, will be seen to consist of a cast-iron base-work, upon which is bolted a large electro-magnet of peculiar construction. The base also carries bearings to receive the axis of the armature and the driving gear. The field-magnet is composed of 14 soft iron bars, 7 of them being placed above, and 7 below the armature. These iron bars are curved to embrace a great portion of the armature above and beneath, and are connected together by iron junction blocks at their ends, as represented in the figure. This arrangement forms the iron core of a large flat electro-magnet, with two central poles as before explained. It is excited by a current passed through 4 flat bobbins of insulated wire, arranged in the manner shown in the engraving.

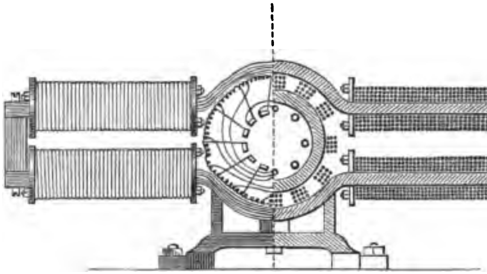


Fig. 53.—Siemens' Machine: Section.

Fig. 52, showing a plan of the horizontal form of machine, will render this arrangement more intelligible. A and A represent the upper portion of the field-magnet, B the armature cylinder, and C the commutator from which the currents are collected.

Fig. 53 is a cross-section of the same machine. In this view, only the half to the right of the diagram is in section, exhibiting the armature and the electro-magnet.

Reverting to Fig. 50, it will be observed that the collecting "brushes," as the commutator springs are termed, are arranged in pairs at diametrically opposite sides of the commutator.

This completes the more essential constructional features of the machine. The field-magnet is excited in two different ways, according to the kind of work the machine is intended to perform. In the first place, the wire coils are so connected together as to act as one continuous length of wire, and this is so disposed as to cause the magnetic polarity of the arrangement to concentrate itself above and beneath the armature. If the machine is intended to work in a circuit not subject to sudden variations of resistance, the magnet coils are made of thick wire, and the whole of the current evolved by the armature is passed through them, and thence to the exterior portion of the circuit. In this arrangement, the whole of the wire active in the machine is in the main circuit at once. This is termed *series winding*.

It will be observed, however, that if an electric lamp were included in the circuit, and if it be of a kind liable to produce great variations in the resistance, an increase of resistance would weaken the current, which, reacting upon the field-magnet, would diminish its power. In this way, great variations in the intensity of the light would be produced, because the current becomes weaker just when it should become stronger, and *vice versâ*.

For these reasons, the electro-magnet of the Siemens' machine is frequently made to act as a "shunt," or derived circuit from the main circuit. In this arrangement, the magnet is wound with much finer wire, and the current from the armature, after being collected by the "brushes," is divided into two parts, the one being passed through the electro-magnet coils, and the other flowing in the main circuit. The effect of this arrangement is that, when the exterior resistance increases, a large proportion of the total current is caused to pass through the electro-magnet, thus increasing the intensity of the magnetic field and the power of the machine to overcome the exterior resistance; and conversely, when the exterior resistance diminishes, less of the current passes through the electro-magnet, and its power is diminished in proportion. A continuous balancing of the power of the magnetic field and the work done in the exterior resistance thus goes on, the power of the machine becoming greater and less as it is required. These machines are called "*shunt wound*" machines. Another arrangement in which the "shunt" and "series" winding is combined is known as "*compound*" winding.

In some forms of the machine, or when several machines are used together to maintain a series of electric lamps, it is found most advantageous to excite the electro-magnets by an independent machine of small size. In the action of one form of the Siemens' machine alternating currents are produced. It is therefore impossible to excite the magnets of the machine itself by means of those alternating currents. In such cases a small continuous current machine, called an exciter, driven from the same engine, is employed. The exciter is generally of the type represented in Fig. 54. It is essentially the same kind of machine as that already described, but of smaller size, and arranged vertically, so as to occupy as small a floor-space as possible.

In one peculiar form of the large Siemens' machine the iron cylinder of the armature is a fixture, and the wire envelope revolves over it. In this case the machine is provided with double sets of bearings, the outer set being merely supports for the central fixed shaft to which the stationary iron cylinder is attached, and the inner pair in which the axis of the wire envelope rotates. The wire is coiled upon a cylinder of German silver, to which the axis and driving-pulley, with the commutator, are attached. The other portions of the machine are the same as those already spoken of.

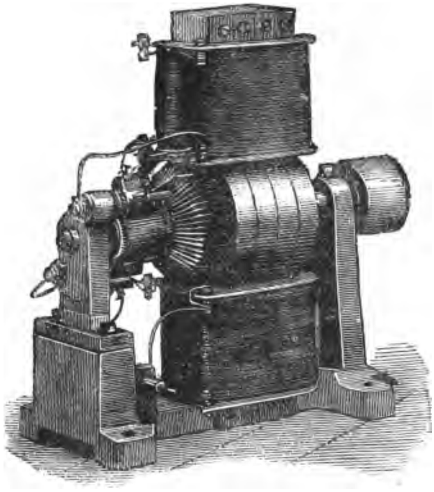


Fig. 54.—Siemens' Continuous Current Exciting Machine.

Fig. 55 represents the fixed cylinder machine in section, the bearings for the fixed shaft being omitted.

When the Siemens' machine is set in motion there is little resistance, but a few turns of the armature are sufficient to collect in its coils, from the feeble induction of the residual magnetism, enough electricity to greatly strengthen the magnetic poles, which induce stronger currents in the coils, and this continues, on the principle of mutual accumulation, until the magnet is saturated and the machine gives its strongest current.

The magnetic poles act strongest upon the coils just as they pass the vertical line passing through the axis, and the weakest currents are produced as the coils pass the horizontal line. These are called the maximum and minimum points. Currents are thus induced as the convolutions of wire approach either of the magnetic poles. The currents are at once taken off by the collecting brushes, and pass in a constant direction through all the coils of the electro-magnet, from the two ends of which the current is taken from the external circuit in the usual way. All the wires employed are, of course, insulated, by being covered with cotton or silk.

The following table contains some particulars of Siemens' continuous current machines (1885):

Type of Machine.	Number of Lights.	Light Power in Standard Candles of each Light.	Diameter of Pulley in Inches.	Width of Machine Strap in Inches.	Number of Revolutions per Minute.	Horse-power required, about—
D_{00}	1	50,000	15	9	400	20
D_0	1	30,000	12	8½	500	15
D^1	1	12,000	10	4	550	7
D^2	1	6,000	8½	3½	600	4
D^7	1	3,000	6½	3	950	3
D^3	1	2,000	7	3	950	2½
D^6	1	1,300	6	2½	1,300	2
D^5	1	500	5	2½	1,200	1½
SD_7	3	1,000	6½	3	950	3
SD_8	6	1,000	8½	3½	950	5½

The above speeds are for a circuit of low resistance; for higher resistances the speed must be increased.

Several lighthouses are now illuminated solely by the above machines. The smallest size would appear to be in most favour, as they may be readily coupled together, which is often required in thick weather to produce a powerful light, which would be unnecessary in clear weather. They have been adopted by the Trinity Board at the Lizard lighthouse, where six of the small machines are fixed. Of the competitive trial brought about by the Trinity Board (1877-83) to determine the most economical machine for lighthouses, superintended by Professor Tyndall and Sir J. N. Douglas, engineer to the Board, it will be unnecessary here to speak at length. The Siemens is known to have given the best results. Of the working of Siemens' machines the author has had practical experience, and can testify to their excellent performance. The machines keep cool, which is a great advantage in continuous working.

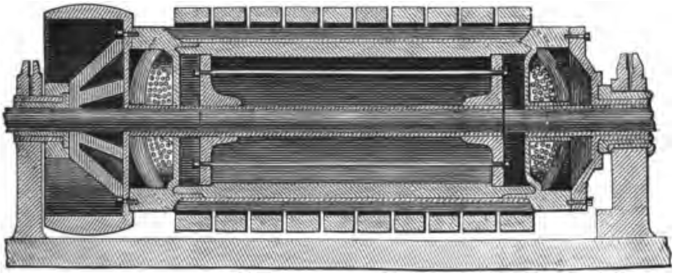


Fig. 55.—Siemens' Machine with fixed armature core: Section.

Ring and Disc Armatures.

If an iron ring be coiled with a continuous spiral of insulated wire, and if it be then rotated in a magnetic field, a current will be set up in the insulated wire. The current may be "collected" by brushes bearing upon the bared wire at semi-diameters transverse to the magnetic field.

Gramme's armature is a good example of this type, the current being led away from a "commutator," the numerous plates of which are connected to the continuous spiral by branch wires. In practice, the armature is constructed, first, of a core, or "ring" of soft iron wire, bearing a number of compactly wound coils, connected as a continuous spiral, each coil being in connection with a corresponding plate upon the revolving collector axis.

If these coils be wound alternately right and left handed, instead of continuous currents alternating currents will be given off.

The practice of constructing alternating current dynamos seems to be drifting largely in the direction of employing a field divided into two circles, as in the Ferranti-Thompson type (page 126), with alternate poles. If a ring wound as above, with *alternating right and left hand spirals*, be rotated in such a field, *continuous* currents will result, because the polarity of the field is continually changing, just as the spirals are changing. It is of course assumed that the field poles and the coils upon the armature are equal in number, or form some multiple of each other, and that the currents are collected as in a Gramme machine.

To obtain *alternating* currents in such a field, the coils must form a *continuous* spiral.

When only a low electromotive is required, as for lighting incandescent lamps in parallel, as in Edison's system of distribution the continuous spirals or coil sections are each connected alternately to the two collector rings rotating with the axis. When it is required to double the electromotive force so halving the current, two coils are connected together and one connection taken from the pair and so on around the circle, or all the coils are connected in series, yielding the maximum E. M. F.

The usual means of collecting the currents from an alternating machine is to arrange the coils alternately right and left handedly, and to connect them in series, the collecting arrangement being simply two gun-metal rings, representing the two terminals, rotating with the shaft.

When the coils are all arranged right handedly, then interior terminal of No. 1 must connect to the exterior terminal of No. 2, and so on—this has practically the same effect as alternate right and left winding.

The field magnet current for such machines is usually furnished by a separate continuous current dynamo, a method which has been found by far the best, especially for large machines.

The currents furnished by alternating current armatures can easily be rendered continuous or uni-direction by means of a suitable commutator.

In addition to the method of winding the coils *around* the substance of the core, various makers have constructed armatures in which the coils form flat hanks, placed simply upon the periphery of the core. In other forms only a non-magnetic or wooden core is used, although the presence of iron has always been shown to greatly augment the power of the machine.

The core should, in all cases, be so laminated or arranged as to render impossible the formation of induction currents in its substance. Thus, a solid iron core would heat rapidly, and lead to great waste of power; while a core of iron wires, carefully insulated from each other, or one built up from stamped iron rings, have been found the least wasteful.

Disc Armatures are now very common. They are usually to be found in that type of machine in which the field-magnets take a multiple form in the shape of two crowns of poles, facing each other. The disc armature is placed between these. The field is arranged so that N is opposed to S, and so on. The armature consists essentially of a series of coils, with or without cores, having their axes in line with that of the machine, and revolving with a disc or "spider" wheel fixed to the shaft.

The coils are usually wound alternately right and left. In the early days of the machine, owing to the solid iron cores used in these coils, the heat generated in them was found to speedily break down the insulation. This led to lamination of the cores, and finally, in some of the best of such machines, as the Siemens and Ferranti-Thompson, to the abandonment of iron altogether.

By the multiplication of such coils, and by increasing the diameter of the disc, the speed of the machine may be correspondingly reduced, a fact which has led to enormous diameters being adopted in large machines.

The Siemens Alternating Current Machine.

Dr. Siemens, in 1878, patented an alternating current machine, Fig. 56. It consists of a central disc carrying bobbins. This disc is on a shaft and revolves between two sets of electro-magnets ranged in circles on each side of the disc, having their axis parallel to the shaft. The bobbins have no iron cores, and the heating caused by the magnetising and demagnetising of the iron is thus avoided. The electro-magnets are excited by a small Siemens' continuous current dynamo machine.

These alternating current machines, which are made in a variety of sizes to maintain from 4 to 60 of Siemens' differential arc lamps, are also adapted for use with Jablochkoff's candles, or with incandescent lamps. Their field-magnets are all excited by continuous current machines of varying sizes; the main machines absorb from 4 to 40 H.P., and the exciters from 1½ to 4 H.P.

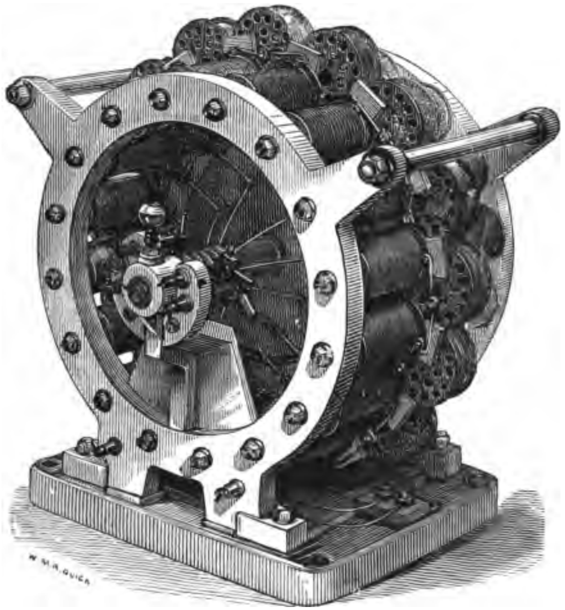


Fig. 56.—Siemens' Alternating Current Machine.

The Ferranti-Thompson Dynamo.

This machine is the joint invention of Messrs. Ferranti and Thompson in co-operation with Sir William Thompson.

Since its introduction, in 1882, it has undergone several modications up to the present time, but a brief description of the "thousand light" machine will serve to give the leading points of the various forms and sizes.

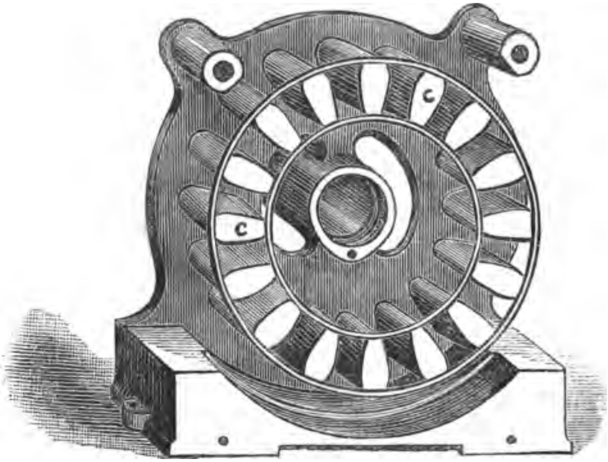


Fig. 57.—Ferranti Dynamo Frame.

The machine consists essentially of two similar sides, each carrying 16 V-like projections of iron, which are in turn enveloped in layers of insulated wire, somewhat after the manner of Siemens' alternator. Fig. 57 will give an idea of the arrangement, and Fig. 58 of the coils to be slipped over the cores C.

When the two frames of the machine are brought into position upon the bed-plate opposite poles have opposite magnetic signs—that is, N is opposite S, and so on around the circle. These two halves provide the intense magnetic field required.

But the armature is the distinctive feature of the machine. It is made in the form of a thin star, with light leaves, Fig. 59. The coils are made, not from wire, but from strap copper, arranged in many layers, in a peculiar way. As originally designed, the armature was intended, we believe, to be formed of a single copper band only. In its present form the armature is built up of three copper straps, forming as many circuits, but connected in parallel. Each layer is in-

Fig. 58.—Ferranti Field Coils.

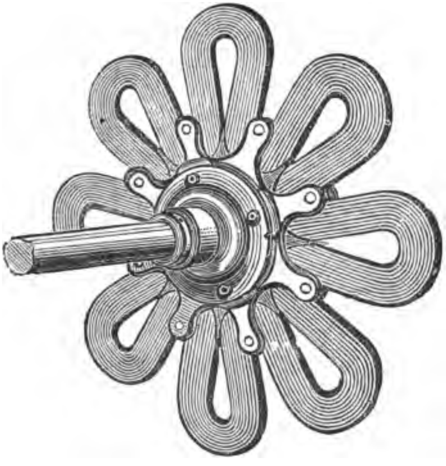


Fig. 59.—Ferranti Armature.

sulated separately. Fig. 60 shows the course of the windings upon the "star." The thickness of the armature is about ½-in., thus allowing the field-magnets to be brought very near to each other and permitting the development of an intense magnetic field (see section, Fig. 61).

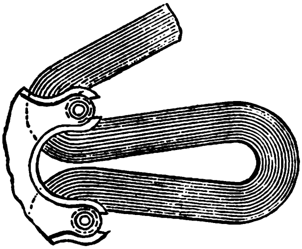


Fig. 60.—Ferranti Armature Loop.

Fig. 62 will give an idea of the external appearance of the machine as built for ship lighting, which, however, in the 1,000-light machine has two driving pulleys, and is built for a speed of 1,400 revolutions per minute.

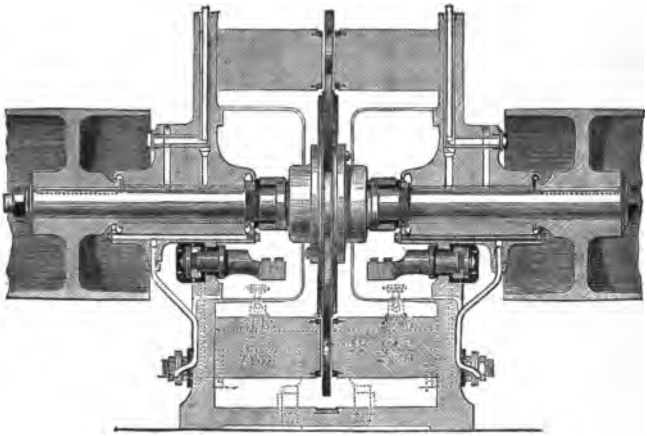


Fig. 61.—Ferranti Alternator—Section.

The "thousand light" machine has the following dimensions, &c. :—

Bed-plate, 39½ × 16 in.; height, 34 in.; shaft, of steel, 2·25 in. diam., 42 in. length; pulleys (2), 15 in. diam., 12 in. face. Field-magnet cores: 7 layers copper wire, 3·5 mm. diam., 48 turns on each layer. The coils weigh 6 cwt. 3 qrs. 20 lbs., total resistance, 7·57 ohms. Armature: each copper strap 14 ft. in length, and two of the three are 1·5 mm. in thickness, the third being 1·75 mm., 30 layers in all. Resistance is stated to be as low as ·005 ohm; weight complete, 3 qr. 12 lbs.

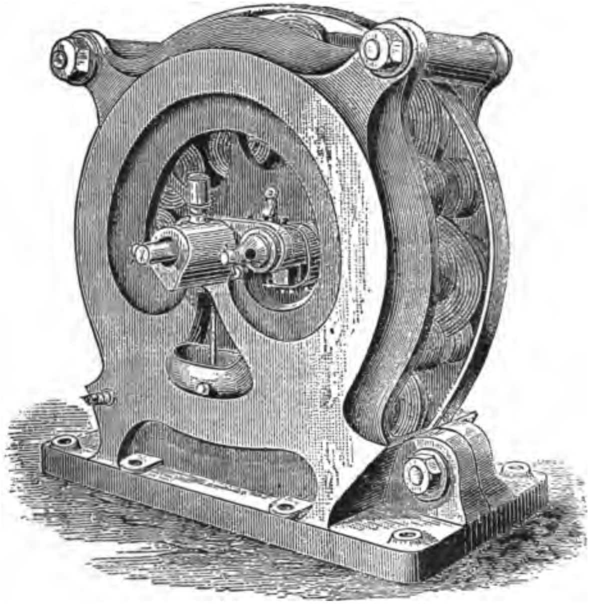


Fig. 62.—Ferranti Alternator.

The currents are taken off two plain rings upon the axis, hook-like collectors being used for that purpose. The field-magnets are excited by a separate continuous-current machine.

The power required, when Swan 20 candle-power lamps are used, is stated to be about 82 horse-power, exclusive of friction, &c.

At the central generating station of the London Electric Supply Company, at Deptford, some very large machines, built somewhat upon these lines, and requiring an expenditure of some thousands of horse-power, are being [1889] erected. Reliable details of these mammoth dynamos are not yet obtainable.

Mordey's Alternating Dynamo.

This is a generator exhibiting some strikingly original features. Its peculiarities are at the same time as valuable as they are novel.

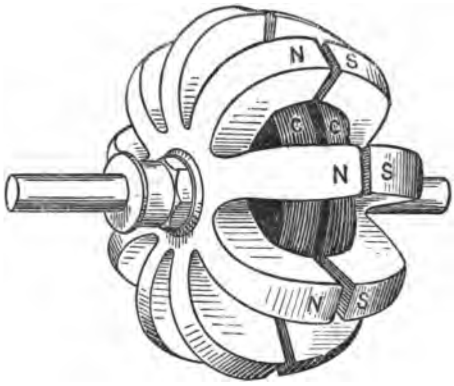


Fig. 63.—Mordey Field Magnet.

The field-magnet revolves while the armature is a fixture; this is not new, but the design and construction of the field-magnet, which is shown in Fig. 63, is decidedly unique. It consists of a series of curving horns, N S N S, facing each other, nine on each side, and leaving only a narrow gap between them. These are of iron, and form the poles. The magnet is excited by a current passed in a double coil, C C, around the central portion of the iron body.

Unlike many other alternating current machines possessing divided magnets, the magnet in this case is of uniform polarity for each crown of poles—or one pole divided into nine branches, all of those upon one side being of south polarity, and those of the other side being north. Great simplicity of construction is thus obtained.

Fig. 64.—Mordey Alternator, Armature.

The armature, Fig. 64, is stationary, and consists of a circle of V-shaped coils of copper ribbon $\frac{7}{16}$ in. wide and 18 in number, wound upon porcelain insulators. Referring to Fig. 63, the distance between the polar horns is just sufficient to allow of the armature coils passing between them. A very intense magnetic field, which passes thus directly through each coil, is obtained, and for this reason the efficiency should be very high.

Machines of the alternator type, which are generally furnished with armatures of ribbon in the form of a thin star, present great difficulties in the matter of giving sufficient rigidity to the armatures. At high speeds not only do centrifugal difficulties present themselves, rendering it a problem to obviate the flying apart of the armature, but a still graver source of trouble has to be faced. It is well known that bodies like ribbon armatures, being necessarily large and light, with but little support, are apt to sag or sway from side to side, or obtain a wave-like motion at high velocities. This would necessarily be intensified by any unequal "pull" of the field-magnets. Such armatures, too, have to bear a powerful drag from the field. These difficulties would be little thought of were there plenty of space available between the field-magnets. But it is just here that the parts must all but touch in revolving, so that, unless power be voluntarily lost by giving sufficient room for accidental undulation, rubbing contacts of a destructive character are apt to occur.

It will at once be discerned that in the form of field-magnet and armature under discussion (Mordey's) these difficulties receive a most satisfactory solution. It will be comparatively easy to produce a perfectly rigid armature, because it is stationary, and the revolving magnet is in itself quite rigid, and in addition is provided with a thrust-block in one of the shaft bearings, which renders the slightest deviation impossible, while accuracy of adjustment is quite simple. It may also be pointed out that the massive magnet forms an excellent fly-wheel to the dynamo, which may serve to smooth down any irregular pulsations from the engine.

The machine under review, which absorbs between 50 and 60 horse-power, and maintains 600 lamps, has an electromotive force of 2,000 volts, at 20 ampères, makes 650 revolutions per minute, and is excited by a separate "Victoria" continuous current dynamo, frequently mounted upon the same base and driven by the same axis. The diameter of the field-magnet is 35 in., and weight of complete machine 2 tons. It is made by the Brush Electrical Engineering Company, London.

Lowrie-Parker Dynamo.

These machines are of two kinds, to give alternating or direct currents.

The large alternator, a photograph of which is represented in Fig. 65, has a stationary armature and a rotating field-magnet. This consists of a soft iron ring, the polar pieces being separately attached. The field-magnet is built upon the central shaft, which is of steel, carried in long bearings. A separate dynamo is used for exciting the field-magnet.

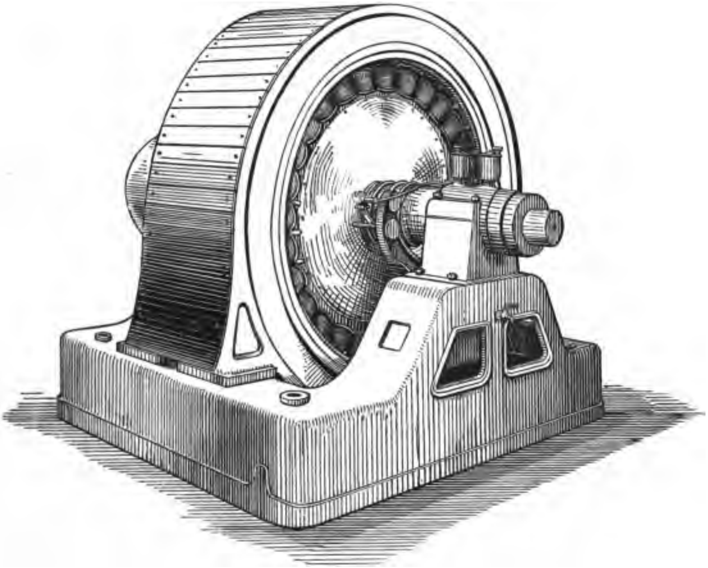


Fig. 65.—Lowrie-Parker Alternator.

The armature is built upon the interior surface of the drum-like frame of the machine. It consists of a core built up of sheets of charcoal iron, on the laminated principle, forming a plain cylindrical surface. The coils consist of copper tape wound in many layers and forming a flat, long link-shape. The ends of these coils are shown in the figure. The cores of the coils consist of an oblong piece of insulating material. The axis of each coil is thus radial to the circle. The number of coils coincides with the number of magnets. The coils are held in position by projecting holdfasts of wood screwed to the frame of the machine, and beyond the path of the magnets.

The machines at the West Brompton lighting station are driven by ropes, the pulley, which is 40 in. in diameter, having 7 grooves for this purpose, to receive as many 1½ in. ropes. The exciting machine is driven off the dynamo shaft. As is usual with large machines the base is placed upon rails, so that the dynamo can be moved by means of screws for the purpose of making up for slack in the driving bands.

Electrical output, 2,000 volts, 50 ampères; speed, 400 revs. per minute; alternations of current per minute, 1,200; resistances: armature, ·65 ohm; magnets, 4·4 ohms; exciting current, maximum 28 ampères: weight of machine, 8 tons.

The large alternating dynamo is excited by the current from a smaller continuous current machine, as shown in Fig. 66, and known as the "12-unit size."*

The 18-unit machine, which is usually employed to run as many as 300 60-watt lamps, is a shunt wound dynamo with a drum armature, of the following dimensions:—

---

* *i.e.*, 12 *thousand* volt-ampères.

Length, 4′ 11″; width, 2′ 4″; height, 3′ 0″; approximate weight, 30 cwts.; speed, 900 revs.

Particulars of similar machine wound for 130 volts, 140 ampères: armature, number of wires on circumference, 120; section of conductor, ·036 sq. in.; resistance, ·021 ohm.; resistance of shunt, 26·4

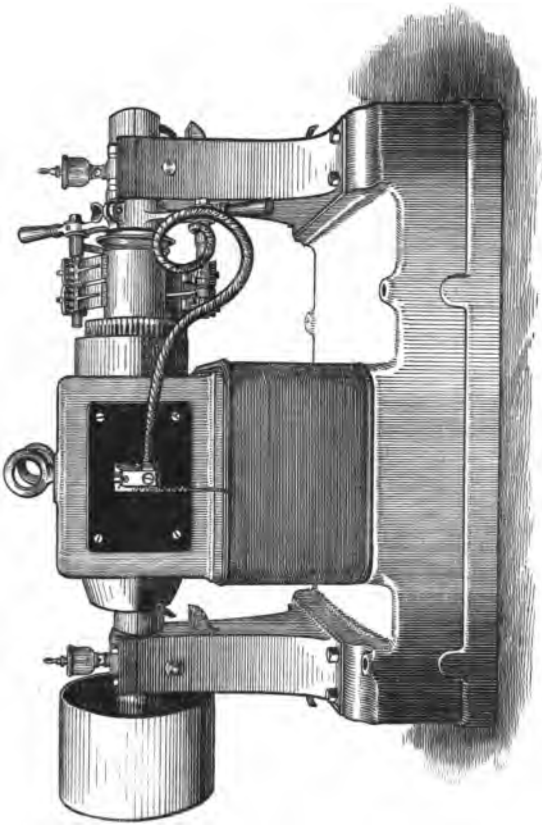


Fig. 66.—12-unit Lowrie-Parker Dynamo.

ohms. Particulars of 5-unit machine: Compound-wound;* speed, 1,200 revs.; length, 4′ 4″; width, 1′ 10″; height, 2′ 4″; approximate weight, 12 cwts.; drum armature.

Maxim's Machine.

Fig. 67 represents a dynamo-electric machine, patented by Mr. Hiram S. Maxim, of New York.

It will not be difficult to trace in the arrangement of the parts a distinct resemblance to the Siemens' machine.

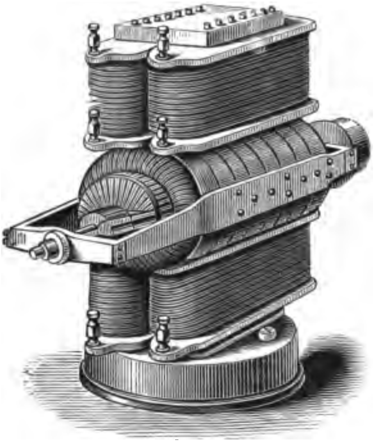


Fig. 67.—Maxim's Machine.

The curved electro-magnet bars are bolted to a stout cast-iron projection from the base, and form, in fact, the framework of the machine. They extend upwards, are curved at the middle to provide a cylindrical chamber for the armature, and are finally bolted to a metallic plate forming the crown of the machine. Just above the base are placed a pair of flat wire bobbins, closely embracing the electro-magnet bars, and above the curved central portion are fixed another similar pair of bobbins. This forms the electro-magnetic system of the apparatus, which is very simple so far.

Along the sides of the bars, just opposite to the central line horizontally, are bolted two stout side

---

* See page 118.

frames. These carry between their ends the supports or bearings of the axis of rotation.

The armature of Maxim's machine consists of a hollow iron cylinder enveloped by numerous convolutions of insulated wire. The arrangement is similar to that of the Gramme armature, the only difference being that the iron portion consists of a cylinder instead of a ring. The enveloping coil consists of 16 helices of copper wire, each helix consisting of 4 wires, the extremities of which are connected to the 64 sections of the commutator cylinder in the manner already described in reference to the Gramme machine. The collecting brushes are attached to an adjustable frame, capable of movement upon the axis, and an arrangement is provided by means of which the brushes may be caused to bear at greater or less distances from the points of maximum currents. This arrangement is made to serve as a regulator of the current by an ingenious adaptation of electro-magnets and adjusting levers (not represented in the engraving), controlled by the current in the main circuit. Maxim's machine is chiefly used in connection with the same inventor's incandescent lamps.

Wilde's Dynamo-Electric Machine.

Mr. Wilde, in 1866, took out a patent which forms the basis of a dynamo-electric machine, which he eventually completed in its design in 1873. It consists, for the framework, of two cast-iron circular plates, placed vertically and kept the requisite distance apart by stay rods. Each plate carries, projecting from its inner face, a series of electro-magnets, sixteen in number. These fill up the greater part of the space between the frames. Through the centres of the frames is passed the shaft, which carries a large cast-iron disc, rotating between the two sets of electro-magnets. This cast-iron rotating disc carries sixteen soft iron cores, passed through the disc. The projecting ends of each core are wound with wire; thus they form 32 armature electro-magnets. These are connected so as to form eight groups of four each, and the current from one of these groups is used to excite the circles of field electro-magnets, whilst the remaining seven groups are employed to give the current for external use. By an arrangement of commutators the currents produced can be obtained direct or alternating. This machine is extensively used by the Admiralty in the large ironclads, where it is driven by a Brotherhood engine connected direct to the shaft.

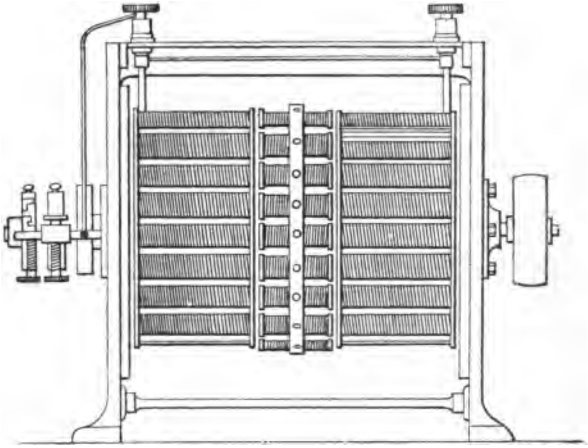


Fig. 68.—Wilde's Dynamo-Electric Machine: Front Elevation.

Figs. 68 and 69 will give some general idea of the arrangement of the parts in this machine.

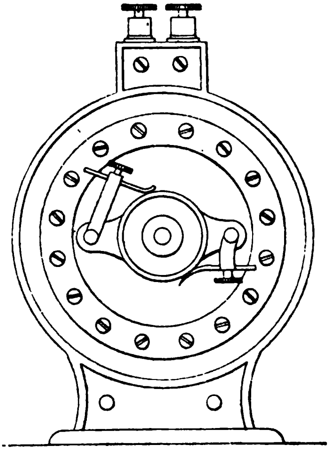


Fig. 69.—Wilde's Dynamo-Electric Machine: End Elevation.

Weston's (Earlier Pattern) Machine.

Fig. 70 shows the external appearance of this apparatus, and Fig. 71 the central arrangement of magnets. There are two sets, the inner, on the shaft, and the outer, fixed to the cast-iron drum. Each set is composed of six magnets. They are arranged in pairs, forming three pairs of horse-shoe magnets. The length is less in the inside set than in the outside set, which is made fast to the iron drum by screws as represented. These magnets are composed of malleable cast-iron, and are of a shape which gives them great inductive strength in little space. It will be observed that, with reference to the outside set of magnets, the cylinder or drum itself forms the magnetic connecting link between them. The drum being of cast-iron, of considerable hardness, permanently retains, as indeed do the magnets themselves, sufficient residuary magnetism to start the machine in action as soon as the central system is put in motion.

After coiling, the wires are taken off in three pairs. Those wires from the N. poles, for example, are carried to one portion of the commutator, Fig. 72, and those from the S. poles to the other portion. The wire is finer for the inner than for the outer set of magnets.

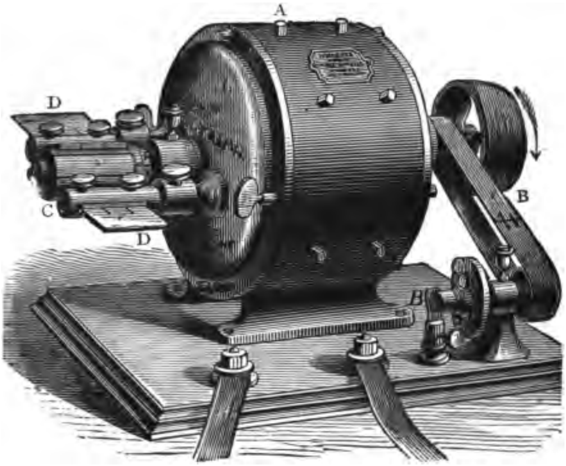


Fig. 70.—Weston's First Machine.

After the currents are generated in the central set constituting the armature, they pass to the contact brushes, and from these they are at once led into the circuit of the outside set of magnets by the ends of the wire shown disconnected in Fig. 71. This can be done because the outside system circuit is complete, the wire being wound, without break, over each bobbin in succession. One contact brush is connected to one end of the outer magnet circuit, and the other is connected to one extremity of the external resistance, the second end of which is connected to the remaining extremity of the magnet portion of the circuit. The contact brushes are shown at D D, Fig. 70.

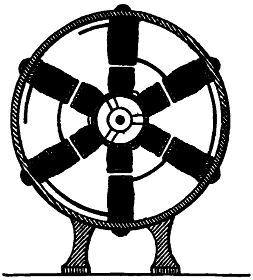


Fig. 71.—Weston's Machine: Section.

Much care is taken so to adjust and turn up the faces of the two sets of magnets that they may pass each other as near as possible without actually touching.

The polarity of the armature system is continually being changed when the machine is in motion, because the outside magnets always have like polarity, and by induction change the poles of the inner system six times in one revolution. The inner system should always, in these machines, be of the softest and finest iron, because the changes of magnetic polarity are exceedingly rapid, and much heating, with loss of current and power, must result in the employment of cast or hard iron.

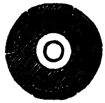


Fig. 72. Weston's Commutator.

Six impulses are given off at each revolution, and as these are in alternate directions, they are converted into three direct impulses by the commutator. Because these currents are not constant in strength throughout each revolution, the speed should be high in employing the machine for electric light. This dynamo is now chiefly used for electro-deposition.

Weston's New Machine.—The general arrangement of this machine is exhibited in Fig. 73, where A A represent the magnet coils. It will be observed that this part of the apparatus is similar to that of Siemens. The pole pieces, or plates, crossing the armature and embracing it for part of its circumference, are composed of iron plates, placed side by side in a mould, but separated a uniform distance from each other. As the plates are thus set in the mould, the iron magnets on which the wire is to be wound are cast on to the "lugs," or projections, on the ends of the plates.

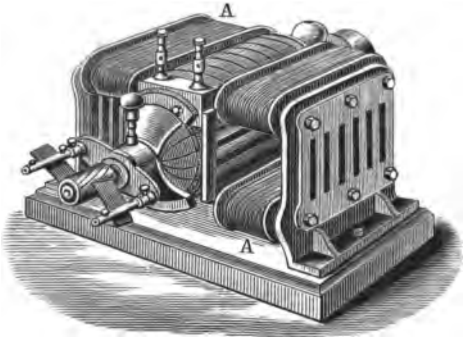


Fig. 73.—Weston's New Machine.

The two cast-iron ends and uniting plates form one magnet; the upper and lower magnets are alike, and when joined together by the perforated vertical supports, the inner curved edges of the field-plates embrace about two-thirds of the circle in which the armature is to revolve.

It will be thus seen that the inventor prefers to employ cast-iron and malleable plate in his magnets, making the crossing curved prolongations only from boiler or other rolled plate.

Fig. 74 represents the unwound armature, or revolving portion of the machine. It is built up of plates which are somewhat like a cogged wheel in shape. These plates are stamped out of sheet iron, and when mounted on the shaft are separated from each other at a uniform distance. The radial projections are then arranged in lines, so that the whole forms a very broad cogged wheel, or cylindrical structure, having longitudinal grooves with transverse spaces at regular distances. The longitudinal grooves are intended to carry the wire, and it will be observed from the nature of the structure that the wire lies in channels three sides of which are iron, so that the mutual effect upon each other is increased as much as possible.

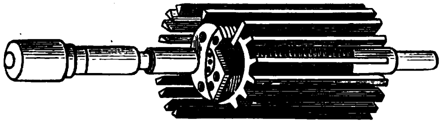


Fig. 74.—Weston's Armature.

The ends of the wire are connected to the commutator in the usual way, the currents travelling in one direction only to the field-magnets. The commutator is fitted on a portion of the shaft which projects beyond the bearings; this admits of its easy removal and a new one being fitted in a few minutes.

Another important feature in the construction is the arrangement for ventilation; the separation between the pole plates of the field-magnets, the perforation in the vertical supports of the magnets, and the light framework of the armature are all for this purpose. The air enters the centre of the armature, and is driven out between the layers of wire through the spaces formed by the separated poles of the armature and field-magnets, and thus prevents any part from becoming unduly heated. Machines of this description are made of various sizes and strengths, to give from one to sixteen arc lights in a single circuit.

This armature should furnish a very good return for the power expended in driving it. Sheet iron is always hard, as rolled by the common process, and unless it is very carefully annealed to secure a softer structure, the magnetic poles of such an armature would not change polarity readily from N. to S., or the converse, in revolution. No doubt, however, the thinness of the various parts composing this ingenious armature will greatly aid its performance in practice.

Dynamo with contact between Armature and Field Magnet.

This machine is the result of an idea that a great gain in power would be obtained by doing away entirely with the space necessary in other machines between the moving and the fixed parts. M. Trouvé

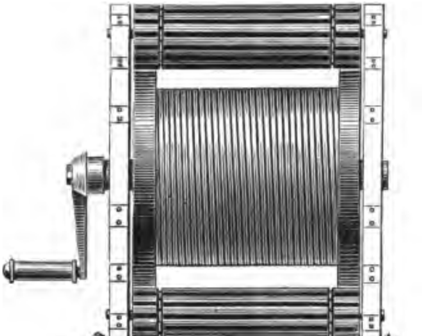


Fig. 75.—Contact Dynamo.

made the large inducing magnet actually touch the cores of the induction coils, and by these means caused the induction coils to revolve also.

Figs. 75 and 76 represent a machine on this principle, where the large central drum is composed of an iron core and ends, wound with wire as usual. This drum-like electro-magnet is surrounded with a frame of spokes at each end, and these frames carry two or more bundles of long, thin induction coils, which revolve in bearings as shown. This motion is caused by friction between the electro-magnet and the small cores. All the cores approaching the large magnet on one side of their circle have, say, negative currents induced, and those receding from it positive. A commutating arrangement is fixed to the axis of each bundle, and from this the currents are taken off, to be used separately (from each bundle) or in combination with those from other bundles of cores actuated by the same electro-magnet.

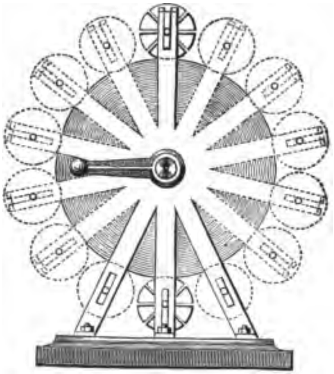


Fig. 76.—Contact Dynamo.

This machine is, without doubt, theoretically good, but would appear to be a step in the wrong direction when regarded from a practical point of view. The friction of the parts is a very great objection, and would consume a great deal of power, with production of heat and much wear. The noise must also be very great, and the whole apparatus complicated, and in large size necessarily costly.

Lontin's Machine.

The machines identified with the name of M. Lontin are intended to produce currents in *a number of circuits from one source.* They consist of a generating or exciting and a distributing machine.

Fig. 77 will give some idea of one of Lontin's first exciting machines, in which several bobbins are arranged on a cylinder and revolve between the poles of the fixed electro-magnets. A commutator is arranged so as to give continuous currents.

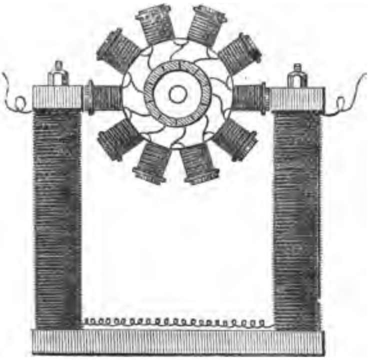


Fig. 77.—Lontin's Exciting Machine.

The dividing or distributing machine is composed of a series of electro-magnets, M M, Fig. 78, radiating from a shaft or drum. These electro-magnets are excited by the continuous current from the machine above described, and cause in their rotation induced currents to flow in the coils wound over the soft iron blocks or cores B B, the circuits being taken from the bobbins B B direct; and those bobbins may be joined in pairs or otherwise, as may best suit the outside resistance to be worked through. The machine is provided with a key-board, upon which are fixed the binding-screws and switches, to cause the currents to be subdivided to a number of lights. This machine, it will be seen, gives alternating currents.

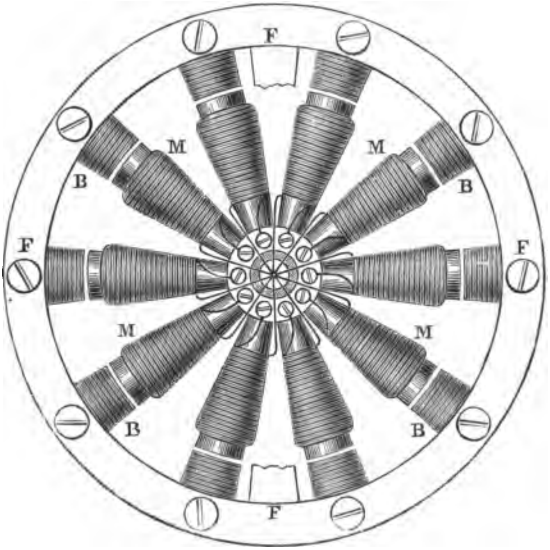


Fig. 78.—Lontin's Distributing Machine.

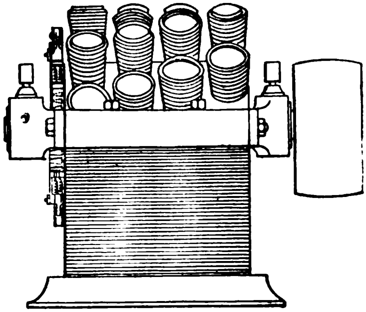


Fig. 79.—Lontin's Exciting Machine.

If there are as many as 10 induction bobbins fixed to the outside frame F F, there will be a possibility of producing 10 lights in as many circuits; or, all those bobbins may be combined to produce one large light, or any number up to 10 as may be required. In this respect the Lontin machine is of much value. It is, in fact, a distributing machine.

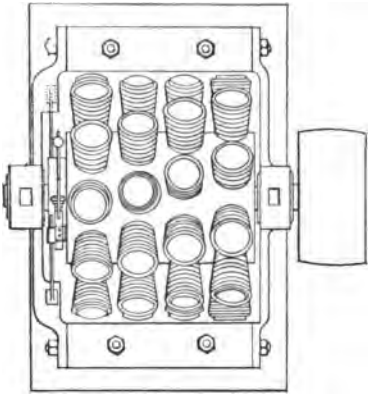


Fig. 80.—Lontin's Exciting Machine: Plan.

In the later machines of this maker the exciting machines have a number of bobbins upon a drum arranged in diagonal lines, as shown in Figs. 79 and 80, revolving between the fixed electro-magnets. By this arrangement the current is maintained more uniform in its strength.

Brush's Machine.

Although the Brush armature presents points of construction similar to those of Gramme's armature, the real difference between the two is greater than at first appears. Brush's ring differs from Gramme's in the arrangement and disposition of the wire helices enveloping it as well as in the method adopted in connecting the coils together. In Gramme's armature, as we have observed, the coils are arranged contiguously to one another, so as to completely envelope the ring, and the different sections are connected together so as to form an endless helix wound upon every part of the ring. In the Brush armature the individual coils are separated from one another by a section of the iron ring as wide as each of the coils themselves. The sectional area of the ring between the coils is also much wider than in that portion enveloped by the coil. This will be rendered clear by the view given of a portion of the ring in Fig. 81. The sunk portions are intended to receive the coils, which fill them up to the level of the projecting sections. In the revolution of the armature between the poles of the field-magnets, the coils alternate with the masses of iron, which, from their enlarged section, are brought into as close proximity to the field-magnets as the coils are themselves.


Fig. 81.—Section of Brush's Armature. Earlier (solid) type.

Reverting to Fig. 81, it will be observed that not only is the periphery of the ring deeply grooved, but that the projections from its sides are separated into several portions by channels. The main object of this is twofold: it is first intended to allow of the circulation of air, and so maintain an even temperature in the ring, which, by rapid magnetic reversals, is very apt to become heated; and secondly, to prevent the development of induction, electric, or magnetic currents in portions of the ring itself, and thus allowing of the concentration of the inductive effect in the coils themselves. In the Brush 16-light machine the armature is 20 inches in diameter, and is wound with 8 radial coils of cotton-covered copper wire of the size known as No. 14 (·083 inch) by the B. W. G. These coils are distributed round the ring at equal angular distances apart of 45 deg. Each coil consists of about 900 feet of wire, weighing about 20 pounds. All the coils are wound in the same direction upon the ring. The two sides of each of the coil-chambers, and therefore of each of the coils, are parallel to the radial plane of the coil, by which means the difficulty of coiling wire in a tapering chamber is avoided. Fig. 82, which is not drawn in strict proportion, exhibits the "solid" form of the ring with the 8 coils in their respective positions.

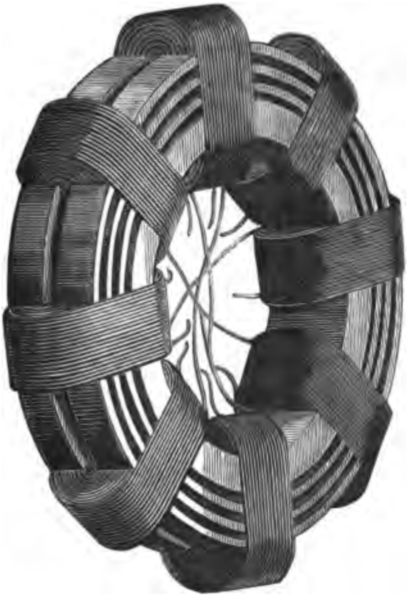


Fig. 82.—Brush's Armature (solid type).

Brush Laminated Armature.

The improved armature with which the Brush machine has been supplied, since 1884, differs in material and constructional detail more than in shape or design from the earlier form here illustrated.

An iron "foundation" disc, mounted upon the shaft, is first provided. Upon this is built up, by a process of winding, the armature itself. The body of it really consists of a close volute spiral of soft iron strip. Separating the successive convolutions of the iron spiral are H-shaped pieces of sheet iron of the thickness of the ribbon. The projecting ends of those separating pieces form the extensions of the armature that separate the coils and pass close to the field-magnets. These projecting portions, or "teeth," are to be found in many forms of armature, and are usually styled "Pacinotti projections" after the inventor who first used them in his armature (p. 71).

The "pockets" or coil-chambers are the spaces between the "Pacinotti projections," and, as in the old pattern of armature, are arranged so as to be parallel to the radial plane of the coil—that is, the spaces are rectangular and not V-shaped. As the building up of the ring proceeds radial bolts passing through the foundation ring and all the successive layers of the armature, with the separating pieces, are passed through, binding all securely together.

Very effective ventilation of the armature is thus secured. But the almost complete elimination of "eddy" currents, which were a source of loss and heating in the old armature, is a far more important matter. It is being recognised that a cool armature does not necessarily imply an efficient one. The armature may be well exposed to the air, and the heat got rid of in this way, but it is better to so build the structure as to render the eddy currents impossible. In the thinnest pieces of iron, however, and under the most perfect conditions of lamination and subdivision possible, a certain amount of heat must be developed, as due to rapid magnetic changes or reversals.

An enormous gain has been secured by the above method of constructing Brush's armature, generally speaking it may be reckoned at 50 per cent. Thus, the "sixteen-light" machine (with the old armature) will, when fitted with the new, give 25 lights. or, otherwise expressed, the new armature will be equal to the old armature, with a decrease of speed of 34 per cent., coupled with a decrease of power absorbed of 20 per cent. The larger machine, which formerly supplied 40 lamps, now yields, with the new armature, an output maintaining 65 lamps. "Lamps" refers to powerful arcs.

The connections of these machines are in some special cases different from those depicted in the cuts. These variations from the regular methods are always made to suit some abnormal condition of the exterior portion of the circuit. For example, in the Brush machines used for electro-deposition it was found practically impossible to maintain a constant potential under varying conditions of load. A method of shunt winding in combination with the series windings was therefore adopted with complete success. It would appear that the Brush machines were thus "compound-wound" for electro-metallurgic purposes long before the same principle was so extensively used in the various methods of parallel electric lighting.

An efficient automatic regulator, with a new kind of relay, devised by Mr. Geipel, of the Brush Company, is in successful use with the electric light machines. See also p. 187.

The usual method followed in connecting up the coils is as follows:—The inner extremity of each of the coils is connected to the inner end of the diametrically opposite coil upon the ring. Thus, if we call the first coil No. 1, its inner extremity would be connected to that of coil No. 5. In the same manner the inner end of No. 2 would be joined to No. 6, and so on round the ring. All the outer extremities of the coils remaining unconnected are insulated from each other and carried to the commutator which rotates with the shaft through a channel provided in the latter. The two free extremities of diametrically opposite helices are connected respectively to two diametrically opposite sections of the commutator. This portion of the machine, forming the surface from which the currents are collected in a uniform direction, is of peculiar construction. It consists essentially of two similar parts, insulated from each other and from the axis of rotation; each part consists of two flat cylinders of copper. The total number of portions is 4, and corresponds with the number of pairs of coils upon the armature. Each of these portions consists of two segments, insulated from each other, and separated by a segment of copper, as represented in the diagram (Fig. 83), where A and B are the contact segments, and C the separating segment referred to. This neutral segment, as we may regard it, is inserted for the purpose of throwing each pair of diametrically opposite helices out of the circuit during that period of their revolution when they are inactive, or for 25 per cent. of the revolution. By these means the inactive pairs of coils are kept out of the circuit, which not only permits of the development of larger currents in the remaining coils, and reduces the resistance of the machine, but is believed to aid in a great measure in preventing the development of heat in the helices.

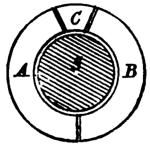


Fig. 83.—Portion of Brush's Commutator.

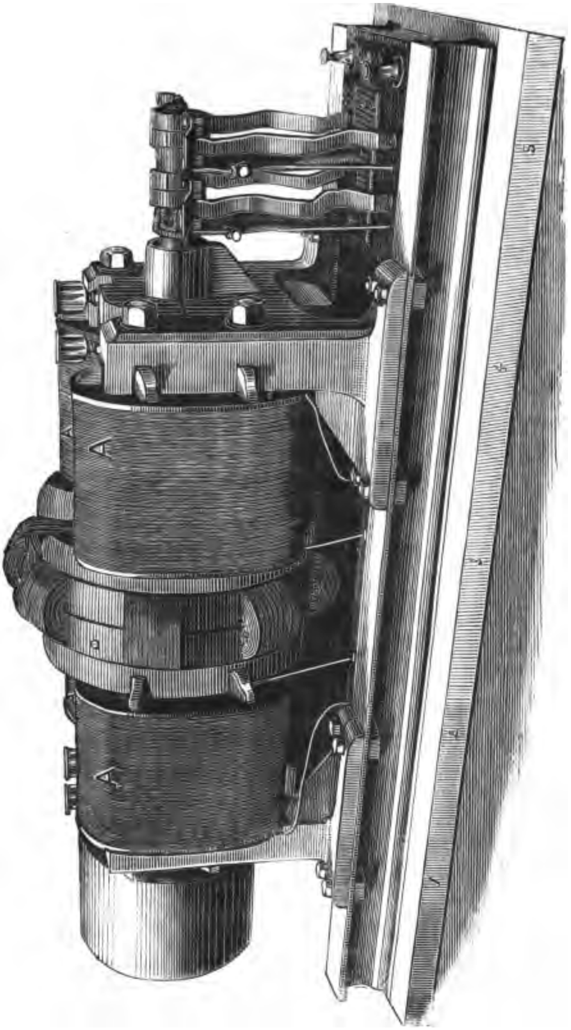


Fig. 84.—Brush's Dynamo Machine.

As will be observed in the general perspective view of the machine, given in Fig. 84, which is from a photograph of the 25-light machine, the disposition of the field-magnets is altogether different from that adopted by M. Gramme. The 4 flat exciting coils, A A, envelope cores of iron furnished with extended polar pieces, which altogether embrace a large proportion of the active surface of the armature. The magnetic system may be regarded as two electro-magnets, with similar poles opposite, and excited by a current passed through the coils, which are connected up so as to form one circuit.

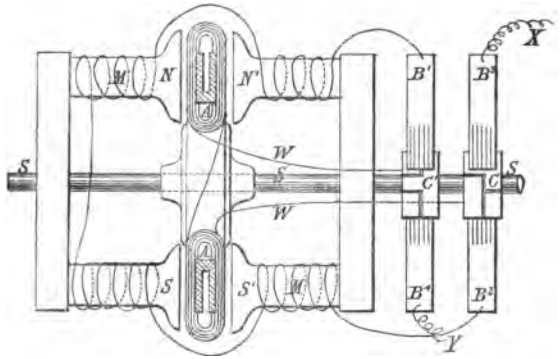


Fig. 85.—Diagram of Brush's Machine.

In Fig. 85 the position and relationship of the field-magnets and armature will be rendered still more intelligible. In this view M M represent the soft iron cores of the electro-magnets, and N S their extended poles. The portions of the framework of the machine connecting the two cores of each magnet are of iron, and we have, therefore, a pair of what is familiarly known as horse-shoe electro-magnets. The arrangement of the wire represents the course of the current around each of the cores. It will be particularly observed that one of the extremities of the wire coils is connected with the collecting "comb" B^1 and the other with B^2. By these means the currents from a certain number of the helices of the armature are made to flow round the field-magnet coils, and those from the remaining helices are utilised for external purposes. In the machine itself the collecting "combs" B B are adjustable in relation to the line of maximum current upon the commutator.

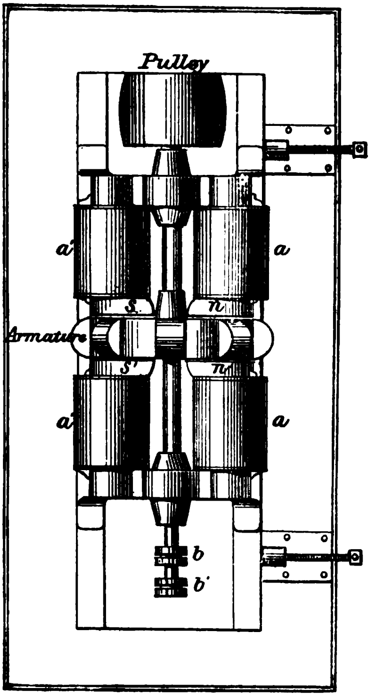


Fig. 86.—Plan of Brush's Machine.

The Figs. 86 and 87 show a plan and end elevation of the machine. The disposition of the polar extensions of the field-magnets is represented at $n\ s$, $s^1\ n^1$ (Fig. 86), $a\ a^1$ being the exciting helices of the magnets; $b\ b^1$ represent the two parts of the commutator and its arrangement upon the free extremity of the shaft.

The total resistance of the 16-light machine is from 10 to 11 ohms; of this the field-magnet helices contribute 0·625 ohm each, and the armature helices about 1·5 ohm each, 6 of which are in circuit at the same time. The brush or commutator contacts increase the resistance of the machine while in action.

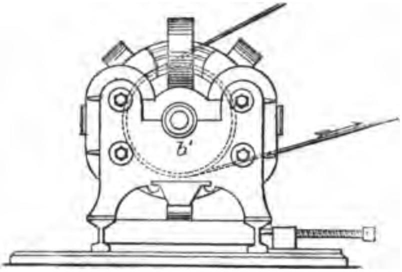


Fig. 87.—End Elevation.

Edison's Machine.

A general view of the first type of this machine is given in Fig. 88. In a large machine of the same kind the arrangement of the field-magnet is horizontal, but the leading features of the apparatus remain the same. It consists essentially of a powerful electro-magnet with two limbs, M M, connected together magnetically by the soft iron yoke-piece, Y, and terminating in the two massive cast-iron polar extensions, *n* S. These are insulated magnetically from the massive base-plate, F, F, which is of cast-iron.

The distinctive features of the apparatus lie in its armature, *a*, which is mounted upon a shaft working in bearings, B B. It is difficult to render the construction of this armature clear by means of a diagram. It consists, Fig. 89, of a core of iron, composed of a large number of soft iron discs, *d d*, insulated magnetically from each other and from the axle, *s s*.

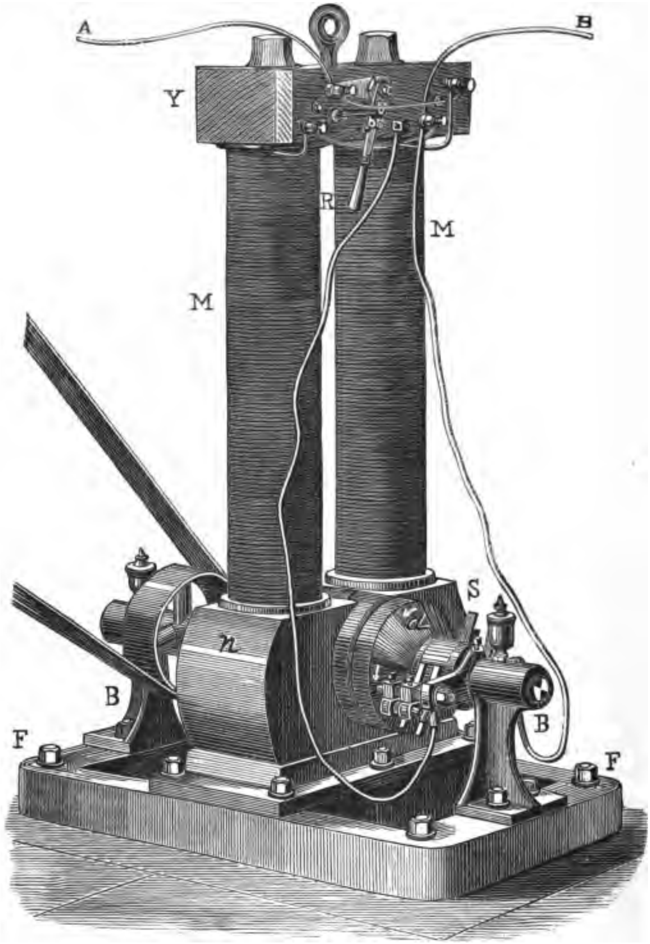


Fig. 88.—Edison's earlier Machine.

These discs are bolted together, and form essentially a solid mass of soft iron rotating with the shaft. So far the construction is quite simple. In order to comprehend the arrangement of the other portions of the armature, the reader may conceive a solid iron cylinder, having coiled upon it, longitudinally, a complete envelope of thick copper wires, wound, not only along its sides, but over both of its ends. We may imagine connections from each of these convolutions to be connected to the collectors of a commutator, and this conception will give a good idea of the armature in Edison's machine. We may indeed carry the conception even further, and compare Edison's armature with that of Siemens, in which wires are coiled in sets around the exterior of an iron cylinder. But in Edison's armature thick copper bars are employed, two of which are represented at *r r* in the diagram. A considerable number of these bars is arranged parallel to the axis of the core, and we may regard them as representing, essentially, the parallel wires of Siemens' armature. The lines *h* and *h* represent two of a series of copper discs, insulated from each other and from the shaft. The spaces filled with transverse dotted lines are occupied by these copper discs. Each disc has two extensions, or "lugs," at opposite diameters, to receive the ends of the copper bars. The real function of these plates is to form connections between each pair of diametrically oppo-

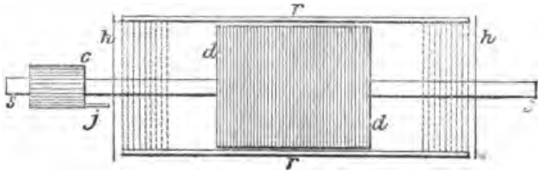


Fig. 89.—Diagram of Edison's Armature.

site parallel copper bars, and the effect of the whole arrangement is to enclose the iron core in an envelope of metallic conductors of exceedingly low resistance. At the end of the armature next to *c j*, each of the copper discs has extended from its central portion a copper "tongue," or junction, in the direction of the commutator, *c j*, and parallel to the axis. These copper tongues are made to slip into the longitudinal channels of the commutator, and therefore serve as the commutator plates or contacts, each tongue, *j*, having its proper groove. It is almost needless to mention that all portions of the armature are carefully insulated and that each convolution forms a circuit in itself; for this purpose talc and other thin insulating substances are employed. The completed armature is enveloped in a covering of paraffined canvas or other suitable material, in order to exclude dust, which would otherwise clog up and short-circuit the spaces between the copper bars and discs. When the armature is of large diameter, it is protected from the effects of centrifugal force by a winding of fine steel wire.

The field-magnet of the machine is excited by a portion of the main currents being shunted into it. For this reason the coils upon its limbs are of comparatively high resistance. The balancing of current to work takes place in this machine in the same manner as has been explained in reference to Siemens' machines. The electromotive force of the machine is about 110 volts.

The large machine lately employed in the incandescent electric lighting of Holborn Viaduct, London, was combined upon one massive cast-iron base, with a Porter-Allen high-speed engine connected to the armature shaft direct, the whole weighing 22 tons. The field-magnet was composed of two separate sets of limbs attached to heavy cast-iron polar pieces. The coils surrounding the limbs of this magnet are connected together in two series, each of which presents a resistance of 12 ohms. The two series are connected in parallel circuit, so that their resistance together, being half that of one of them singly, is reduced to 6 ohms. The gauge of wire employed is Brown and Sharpe's No. 10.

The armature is built upon a steel shaft 6 inches in diameter. Over a core of soft iron discs is arranged the system of copper bars, 106 in number, of an average length of 52 inches, and ½ inch in thickness. These are connected together by means of 53 copper discs, each 26½ inches in diameter, after the manner previously explained. The parts of the armature are insulated by means of ebonite and mica. Every alternate rod in the armature is connected by a radial copper bar with the contact blocks of the commutator, of which there are 53. The commutator cylinder is 12¾ inches in diameter. The resistance of the armature from brush to brush is only ·0049 of an ohm. The field-magnet is excited by a portion of the current on the shunt principle before spoken of. The Porter-Allen engine is of 40 nominal H.P., with cylinders 11 by 16 in., the steam being cut off at about half-stroke. The speed is 350 revolutions per minute, and the indicated H.P. is about 125. This great machine is capable of maintaining 1,000 of the Edison incandescent lamps, each of 16-candle power. The apparatus, as employed at Holborn Viaduct, yielded an illuminating effect of 128 candles per H.P. In the several installations of the Edison system in New

York, 12 of these great machines are used, developing similar effects.

The current evolved by the armature of the Edison machines is controlled by means of resistances inserted in or withdrawn from the exterior portion of the field-magnet circuit. These generally consist of copper or iron wires, coiled around frames, with arrangements for including a greater or less length of wire in the circuit, as required by the circumstances of each case.

Edison-Hopkinson Dynamo.*

Dr. John Hopkinson has considerably modified the original Edison machine. The result has been a remarkable increase in the efficiency and a diminution of size, power for power.

The improved machine as now constructed by Messrs. Mather and Platt, of Manchester, is represented in Fig. 90, which exhibits a bar-armature dynamo for 440 revs., 50 volts, 1,000 ampères. Height 68½ ins., length (axial) 69 ins.; weight, gross, 108 cwt. The limbs of the field-magnet have been considerably shortened, and their diameter increased, as compared with the earlier Edison machine. Dr. Hopkinson also introduced the improvement of winding the magnet with a wire of square section, so economising space. A very full account of the machine is given in a paper by Drs. J. and E. Hopkinson.† The information furnished refers to a dynamo intended for an output of 320 amps. at 105 volts, at 750 revs. The field-magnet limbs are of rectangular

---

* The machine generally known as the "Edison-Hopkinson Dynamo" has field-magnet limbs of rectangular shape.

† See *Philosophical Transactions of the Royal Society*, Part I., 1886.

section and are formed solid of forged soft iron. The bed-plate is of cast-iron, with a footstep of 3 in. 12·7 c.m. in thickness for the reception of the field-magnet. The armature core is built up of 1,000 discs of annealed iron, magnetically insulated by discs of paper. The following are the dimensions :—

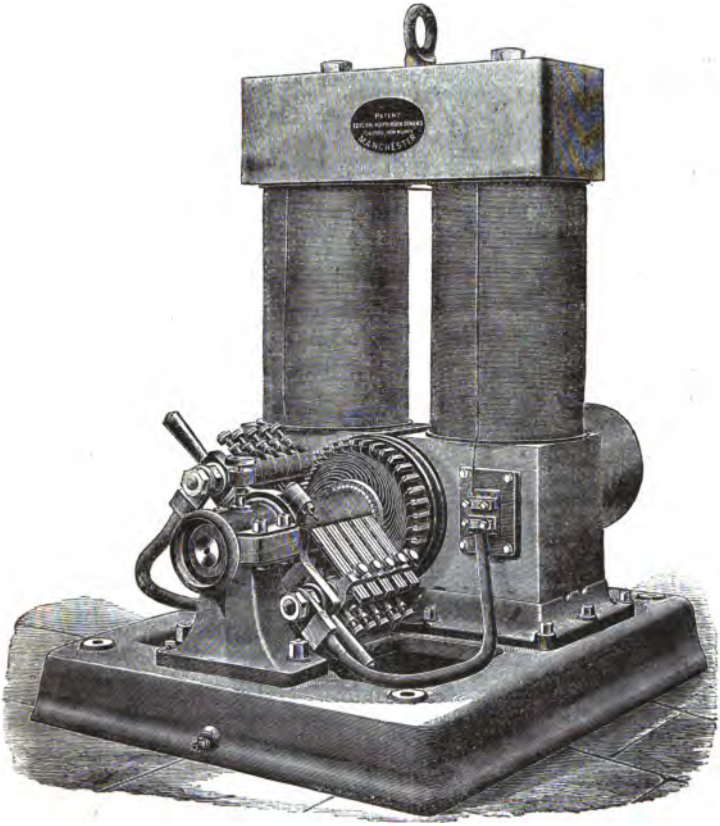


Fig. 90.—Edison Dynamo—Improved Type.

Diameter of armature core, 25·4 c.m., of shaft hole, 7·62 c.m., of shaft, 6·98 c.m.; length of core, 50·8 c.m., of field-magnet limb, 45·7 c.m.; breadth, 22·1 c.m.; width (parallel to shaft), 44·45 c.m.; length of yoke, 61·6 c.m.; width, 48·3 c.m.; depth, 23·2 c.m.; diameter of bore of field-magnet, 27·5 c.m.; depth of pole piece, 25·4 c.m.; width (parallel to shaft), 48·3 c.m.; width between pole pieces, 12·7 c.m.; area of section of iron in armature core, 810 sq. c.m.; angle subtended by bored face of pole pieces, 129°; actual area of pole pieces, 1513 sq. c.m.; effective area, 1.600 sq. c.m.; thickness of gap space, 1·5 c.m.; area of section of limbs, 980 sq. c.m., of yoke, 1120 sq. c.m.

The machine is wound as follows:—Field-magnet coils, 11 layers on each limb, copper wire 2·413 m.m. diameter. Number of convolutions 3,260; total length, 4,570 metres. The armature is either built up of copper bars, as represented, or wound with stranded conductors. In the size of machine to which the foregoing dimensions refer the armature is wire-wound, as follows:—20 convolutions in two layers, forming 40 convolutions. The strands are made up of 16 copper wires 1·753 m.m. diameter. Resistance of field-magnet (at 13·5° C.), 16·93 ohms; ditto of armature 0·0009947 ohm. Magnetising current, 6 ampères. Commutator, 40 sections of copper, insulated with mica.

As shown in the engraving, the connections from the wire strands or copper bars (the latter are shown) are carried to the rear (in the direction of rotation) to a point about 85°, in order to bring the neutral points to convenient positions.

The most characteristic feature of the Edison-Hopkinson dynamo, and that which distinguishes it especially from its predecessors of the same type, viz. the Siemens and Edison dynamo, is the great intensity of the magnetic field and the lowness of the armature resistance. It is these characteristics which contribute most largely to secure its high efficiency, but they also have the incidental advantage of making the machine almost self-regulating without the device commonly known as compound winding. This property of self-regulating will allow the load to be raised within considerable limits without materially affecting the electromotive force of the machine, so that the lamps maintain the same brightness, even though their number be largely varied. If, however, absolute self-regulation be essential, so that the potential shall not vary as the load is increased from zero up to its maximum value, then the machine can be compound wound with every advantage.

The commutator brushes in the Edison-Hopkinson machines are invariably arranged in sections, from two to five, so that any one can be removed and trimmed without disturbing the circuit. The neutral points and the position of the brushes are so arranged that sparking at the commutator is entirely obviated. The commercial efficiency of the latest machines of this type is very high, probably as great as 93 per cent.

The Wallace-Farmer Machine.

Fig. 91 represents this machine. It is of American manufacture, and has been much spoken of as that formerly employed by Mr. Edison, in his first electric-light experiments.

The inducing magnets are flat in shape, and are two in number, attached to the frame. This machine is in reality only an extension of the principle upon which Clark arranged his two-bobbin armature.

Instead of the armature being a straight bar, carrying a pair of bobbins and cores before the magnet poles, two iron discs about an inch apart are employed, studded all round with bobbins and cores, one set to each disc. The poles of the inducing electro-magnet are thus as far apart from each other as the diameter of the bobbin wheel, or nearly so. There are four collecting brushes and two commutators upon the axis where the currents are taken off. The bobbins may be coupled up for tension or quantity. The shaft is carried through, and runs in bearings in the side uprights. Each of the discs may be driven separately, by means of one

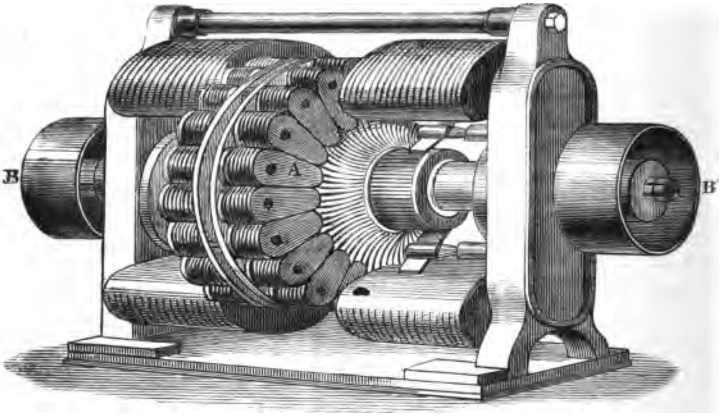


Fig. 91.—Wallace-Farmer Machine.

of two pulleys, B B^1, or they may be coupled together, to be driven from one of the pulleys.

The electric impulses given off by each bobbin are of necessity of very short duration, but as the speed is high, these combine to give rise to a continuous current. The construction presents a large surface to the cooling effects of the air, but this also introduces a disadvantage, as the various parts act as a fan, which causes the air to act an appreciable part in consuming the driving power necessary. The high speed—800 per minute—causes the armature wheel to give out a humming sound when in motion, proving the fan-like action of the bobbins.

Variously different arrangements of the magnets, connections, and commutators may be made in this machine. The practice, however, is to oppose to each other the poles of the magnets, so that the poles of the bobbin cores change polarity during every half-revolution. The wires are connected up so as to pass the currents from the coils, after they have been commuted to one direction, through the inducing magnets, as in other forms of dynamo-electric machines. The collecting points are arranged similarly to those in Gramme's machine, the wires being connected to metallic sectors insulated from each other. Appended are some useful particulars of the wires employed and the work done.

	Copper Wire on Armature.		Copper Wire on Magnets.	
Large Wallace .	0·42 in.	50 lbs.	·114 in.	125 lbs.
Small ,, .	0·43 ,,	19 ,,	·096 ,,	41 ,,

Work.—The weight of the large Wallace machine is 600 lbs., of the smaller size 350 lbs. The armatures or bobbin wheels revolve, 800 revolutions in the large per minute, and 1,000 revolutions in the small machine. The horse-power required is, for the large 4½, and 3½ for the small machine. The illuminating power, in standard candles, is, for the large machine, 823, and for the small, 440. Or, per horse-power, 113 for the smaller machine, that given by the large machine not having been determined.

Figures concerning the consumption of carbon by these machines were given by the committee appointed by the Franklin Institute to test them, particulars of which will be found in the tables relating to the output of machines given further on. The diameter of carbon rods used for the larger machine was ⅜ in., and ¼ in. for the smaller.

The Bürgin Machine.

The field-magnet of this machine is arranged in the same way as that of Siemens' continuous current machine.

In the space occupied by the Siemens armature is placed an armature composed of several circles of soft iron wire or tape wound with several helices of insulated wire, forming in all (in the 3-light machine) 48 coils, each composed of wire ·065 inch in diameter, and 48 feet in length. The weight of the wire is 25 lbs. The soft iron core of each of the rings forming the armature system, is supported by arms radiating from the shaft. The coils are connected together to form an endless helix, as in Gramme's ring, and junctions are taken from the connection points to the commutator plates, of which there are as many as there are junctions or coils. The electro-magnet carries four flat coils of wire, each 750 feet in length, and having a total weight of 140 lbs. The resistance of the armature is 1·6 ohm; of the magnet, 1·2 ohm, giving a total resistance between the terminals (when the machine is so wound that all the current flows around the magnet) of 2·8 ohms. The electro-motive force developed by the machine at its normal speed (1,500 revs.) is 195 volts, and when the speed is increased to 1,600 revs., 206·5 volts, through a resistance, in both cases, of 13·16 ohms. The velocity of the mean diameter of the armature coils through the magnetic field is, at 1,500 revs., 2,550 feet per minute. The greatest current the machine can develop with safety is about 25 ampères. The electro-motive force is found to vary directly with the speed between 1,000 revs. and 1,700 revs.

The total length of the machine over shaft is 2 feet 10 inches; height to terminals, 1 foot 1·5 inch; width, 2 feet 4 inches; weight, about 6·5 cwt.

Some interesting experiments were made with the Bürgin machine by Messrs. Crompton and Co., at King's Cross Station, in July, 1881. It was found that, with the machine running at 1,480 revs. per minute, with 3 arc lamps in circuit, a current of 16 ampères was evolved at the expense of 1·49 H.P. per lamp. With improved arrangements later on, the machine gave, with 1,140 revs., a current of 14·8 ampères, at 1·37 H.P. absorbed per lamp. It was found, by means of balancing by iron wire, and measuring that by Wheatstone's Bridge, that with three lamps in circuit, the resistance was 9·36 ohms. Carré's carbons of 13 millimètres diameter were used. The total resistance was 13·26 ohms, namely, that of lamps 9·36 ohms, leading wires 1·1 ohm, machine 2·8 ohm. Deducting 1·5 ohm as the resistance of each lamp (carbons, connections, etc.) the resistance offered by the voltaic arcs was 8·76 ohms, or about 65 per cent. of the whole. Therefore, about 65 per cent. of the horse-power appeared in the arc as light.

Dynamo with Spherical Armature.

Professors Thomson and Houston, of Philadelphia, have introduced a most unique and efficient form of dynamo. Its most striking feature lies in the shape of the armature, and the corresponding form of the field-magnets. The exterior of the armature is a slightly elongated sphere—in the direction of its axis. The field-magnets form cup-like recesses into which the armature fits very accurately.

In this way a greatly extended active surface can be secured for inductive work, and the speed of the machine may be correspondingly reduced.

The wire system upon the armature is divided into sixteen sections, wound upon every portion of its active surface, and connected in a peculiar way. The field-magnets are compound wound—that is, are both series, of low resistance, and shunt of high resistance. A peculiar feature in connection with the commutator is an arrangement intended to regulate the output to the work doing, by a means of changing the position of the collectors. Another unique device is a self-acting blower, which delivers a "puff" of air under the brushes so as to secure the extinction of any sparking that may take place there.

Notes of some of the more important Dynamo Patents, &c.—Gramme's machine, Nos. 1668, of 1870, and 953, of 1878; Alteneck (Siemens dynamo), No. 2006, of 1873; Brush dynamo, No. 2003, of 1878; Thomson-Houston, No. 315, of 1880; Weston, Nos. 4280, of 1876, and 2194, of 1882; Edison, Nos. 4226, of 1878, 2402, of 1879, 1240 and 2954, of 1881, and 2052, of 1882; Hopkinson, No. 973, of 1883; Wilde, No. 1228, of 1878; Westinghouse, Nos. 9725 and 9727, of 1887; Ferranti, Nos. 3702, of 1883, and 702, of 1887; Mordey, No. 8262, of 1887.

Important Papers relating to the Theory of the Dynamo.—Clark-Maxwell, Proc. Roy. Soc., March 14, 1867; Hopkinson, Proc. Inst. Mech. Engineers, 238, 1879, and 266, 1880; Clausius, Phil. Mag. xvii, 49 and 119, 1884; Hopkinson, J. and E., Phil. Trans. i. 331, 1886; Sir W. Thomson, Journal de Physique, ii. 240, 1887; Kapp, Journ. Soc. Tele. Engineers, xv. 518, 1887; Ayrton and Perry, *Electrician*, xx. 555; Prof. S. P. Thomson, *Electrician*, xxi. 43; Jamison, *Electrician*, xxi. 487, 515.

CHAPTER VII.

GENERAL OBSERVATIONS ON MACHINES.

Size and Capacity of Dynamo.

A GOOD deal of controversy has of late taken place upon the relation that is supposed to subsist between the linear dimensions of dynamos of similar design but of different sizes, and their capacity and efficiency.

According to Dr. Hopkinson,* the capacity of similar dynamos is proportional to the cube of their linear dimensions: the work wasted in magnetising the field magnets proportional to the linear dimensions; whilst the work wasted in heat in the armature is proportional to the square of the linear dimensions.

Mr. Kapp † assumes the speed of rotation to vary inversely as the linear dimensions, so as to put all machines under equal conditions with reference to centrifugal strain. Under those conditions it is assumed that the relative output should vary as in the following table, which gives the leading particulars of two dynamos of different sizes.

Diameter of armature	10 ins.	15 ins.
Revolutions per minute	1,000	670
Number of glow lamps	150	620
Weight (cwts.)	10	34
Price	£100	£276
Price per lamp capacity	13s. 4d.	8s. 11d.
Electrical efficiency (per cent.)	80	89

---

* Proceedings, Institute of Civil Engineers, April, 1883.

† Ibid. vol. lxxxiii. p. 36, 1886.

Several French investigators place the capacity as low as the square linear dimensions, and for this reason prefer small machines.

The general opinion in this country and in America appears to follow the conclusions of engineers in reference to large and small steam-engines, that large dynamos are an enormous advantage, and that, roughly speaking, the capacity of dynamos is, for similar machines, somewhat greater than in proportion to the gross *weight.* The following example, taken from the list of a well-known maker of dynamos, will illustrate this:—

Diameter of armature	8 ins.	10 ins.
Weight ,, ,,	3 cwt.	3 cwt. 3 qrs.
Speed of rotation (revs. p. m.)	1,250	1,100
Gross weight of dynamo	21 *cwt.* 2 *qrs.*	32 *cwt.*
Number of glow lamps maintained	200	400
Price	£140	£200

Testing Dynamos for Efficiency.

To obtain reliable tests of different machines is a matter which has always been attended with some difficulty. It is necessary, first, to determine the horse-power expended in moving the machine, on open circuit (for friction), and with the full load of lamps; secondly, to determine the energy of the currents realised.

Horse-power is measured by one of the usual methods so well known to engineers, viz. by *indicator*, by *dynamometer*, or by *brake*, and need not therefore be treated here.

Electrical output may be determined by ascertaining the number of volts of potential and the number of ampères of current between the extremities of that portion of the circuit in which the energy is being expended. The "voltage" is ascertained by means of a suitable *volt*-meter, and the ampères by means of an *ampère*-meter. Hence the product of the volts into the ampères (volt-ampères) is an expression of the electrical energy per second in "watts" (volt-ampères). Now, as 1 h.p. is equal to 746 watts, the number of watts must be divided by 746 to show the result in h.p.; or,

$$W = \frac{e\,c}{746}$$

where e represents the "voltage," c the ampères, and W the electrical energy realised.

Drs. J. and E. Hopkinson[*] proposed and elaborated an electrical method of testing dynamos, which has been much spoken of. It involves the use of two similar machines, but appears to possess many advantages.

Two dynamos approximately equal in dimensions and power have their shafts coupled by a suitable clutch, which may also serve as a driving pulley. The dynamos are electrically connected together, so that one drives the other as a motor. Upon the driving pulley is placed the belt from the steam-engine. This belt passes on its way to the pulley through a transmission dynamometer. Accordingly, when the machines are in motion, it will be seen that one of them drives the other as a motor, and that the energy required from the steam-engine is the waste in the two dynamos and the friction. In this way very great accuracy is easily attained in arriving at results; for while it is extremely difficult to eliminate

---

[*] *Philosophical Transactions of the Royal Society*, p. 347, 1886.

errors as large as 5 per cent. when the power to be measured is large (say 50 h.p.), with a small power the error may easily be made as small as ½ per cent.

In the experiments at Messrs. Mather & Platt's, Manchester, a pair of Edison-Hopkinson machines, intended for a normal output of 110 volts and 320 ampères, at a speed of 780 revolutions per minute, were used. They were of the shunt-wound type.

The electrical energy was measured: volts by a Thomson's graded galvanometer, and ampères by passing the current through a known resistance, and measuring the difference of potentials at the terminals of this resistance by means of a Clark's standard cell and a potentiometer, according to what is well known as Poggendorff's method. The machines had the following resistances:—

Generator	Armature	0·009947 ohm.	Motor	0·009947 ohm.
	Magnet	16·93 ohms.		16·44 ohms.

The results are so full of interest, as throwing light not only upon the subject of the efficiency of dynamos, but upon the great question of the reconversion of electrical into mechanical energy, that we give in full the figures of one out of a large number of experiments:—

E. M. F. at terminals of generator .	110·12 volts
Current „ „ .	358 ampères
Current through generator magnets .	6·5 „
„ „ motor „ .	5·36 „
E. M. F. at terminals of motor . .	107·33 volts
Speed of machine	764 revs. per minute
Power transmitted by belt . . .	6,604 watts = 8·850 h.p.

Hence—

Total power given to generator . .	42,917 watts = 57·53 h.p.
Power lost in internal friction of armature core.	831 „ = 1·11 h.p.
Power lost in generator magnet . .	716 „ = 0·96 „
„ „ armature . . .	1,360 „ = 1·823 „

and, therefore,—

Commercial efficiency	93·23 per cent.
Loss in core	1·94 „
„ magnets	1·66 „
„ armature	3·17 „

Similarly for the motor—

Total power given to motor	38,886 watts	= 52·13 h.p.
Power lost in internal friction of core	831 „	= 1·11 „
„ „ motor magnet	472 „	= 0·63 „
„ „ armature	1,275 „	= 1·70 „

and, therefore—

Commercial efficiency of motor	93·79 per cent.
Loss in core	2·14 „
„ magnets	1·22 „
„ armature	3·27 „

High Efficiencies.—The above efficiency of 93·23 per cent. is very high, but it is by no means rare in many types of machine now constructed. It will be seen that the dynamo, as a convertor of mechanical into electrical energy, is now probably as nearly perfect as it will ever become.

Measurement has been made by Dr. J. Hopkinson and by Mr. L. Schwendler, independently, of the energy obtained in the form of current from a Siemens machine as compared with the energy shown to be consumed in driving it, and the result showed that only from 12 to 13 per cent. of the energy is wasted, but as lamps are usually adjusted, only half the energy of the current appears in the arc, or 44 per cent. of the energy transmitted by the strap.

Many machines churn the air so that a continuous humming noise is produced, and from 1 to 25 per cent. of the total driving power is thus expended upon the air alone. One machine examined wasted 17 per cent., and it is probable that such types of generators would heat to an inconvenient extent were it not for this air-churning.

With regard to the amount of light (in the arc) produced per horse-power this varies considerably in different machines. Experiments were made at the South Foreland by the Engineer to the Trinity Board, the results of which are given in Sir James Douglas's paper read at the Institution of Civil Engineers in March, 1879. The following are a few of the results obtained.

Machine.	Light produced per H.P. in standard candles, mean of experiments.
Holmes's Magneto-Electric	475
Alliance ,,	543
Gramme, No. 1	758
,, No. 2	758
Siemens' Large	911
,, Small	954
,, Small	1,254

Thus it will be seen that a good machine should give about 1,000 or 1,200 standard candles per horse-power in the electric arc; but the measurement of the light is, in fact, rather a difficult and doubtful matter, owing to the errors caused by the varying position of the carbon points, and the difficulty of obtaining a reliable standard of comparison.

With reference to the light power obtained per H.P. in the case of lighting by incandescence, it may be of interest to remark that in the trial performances of the Ferranti-Thomson machine, from 12 to 14 of Swan's 18-candle incandescent lamps were maintained per H.P. consumed. But it is not certain whether every one of the lamps in circuit was raised to its full photometric value. The above number of lamps per H.P. would appear to indicate that it is possible to obtain about 230 candles' light per H.P. consumed by the machine. In the trial referred to the Ferranti-

Thomson machine absorbed altogether 35 H.P., and maintained from 300 to 320 of the 18-candle Swan lamps in a state of incandescence.

Treatment of the Dynamo.

Commutators.—It may appear curious that if a dynamo is not attached firmly to a rigid foundation its commutator cannot last long or keep in good order. Any vibration of the body of the machine is very likely to be communicated to the brushes, especially if the brackets carrying these are of flimsy construction, with the result that they are apt to partially lose contact with the commutator periodically. In dynamos developing high tension such a condition would speedily produce "flats" or facets upon the surface, and when once a "spot" of this kind is commenced it is sure to spread and deepen.

The life of a commutator is, of course, greatly dependent upon the tension of the machine (its sparking propensity); upon the methods of connection and windings of its coils; upon the position of contact of the brushes (line of least sparking and greatest efficiency—not always coincident); upon the pressure and material and shape of the brushes; and upon the material with which the segments of the commutator are insulated. In shunt-wound machines there is usually less sparking than in series excited machines—when the extremities of the shunt are connected to the two brushes.

In the Thomson-Houston dynamo for arc lighting a considerable electro-motive force is produced. The sparking at the commutator is considerable. But it is remarkable that in high tension machines, where the *current* is correspondingly small, such sparking is not very harmful to the commutator. As the machine is at present arranged it is probably impossible to eliminate this sparking, which in a large machine appears considerable. But an ingenious device is employed to *blow out* the sparks just as they appear. A small air-blast is used for this purpose, and answers the purpose extremely well. In most arc-lighting machines indeed the sparking is necessarily a cause of some trouble, and burnt spots will appear in spite of every care. The air blast presents the great advantage of keeping the surface cool and blowing away any copper dust that may lodge.

Moreover, the line of least sparking is not necessarily the line of maximum efficiency, as remarked above, and any diminution of sparking obtained by rocking the brushes towards the former point may seriously weaken the current and E.M.F.

The pressure of the brushes is a matter of moment. It should never exceed that necessary to give a good contact. It should, on the other hand, be sufficient to withstand the vibration of the machine when in motion. Many dynamos possess a vibration produced within themselves. That is, the magnetic rupture, when the coils pass the field, may and does produce an internal vibration of the commutator and brushes. Pressure must therefore be sufficient to overcome this.

It is perhaps impossible to say what shape constitutes the best collecting brush. A bundle of wires is troublesome; a bundle of copper sheets is also difficult to adjust. Many of the best dynamo makers have adopted a brush composed of two or more copper slips soldered together at one end, and cut into a comb-like shape at the collector end. The object to be aimed at is the sub-division of the spark and the securing of an equal contact, notwithstanding that the commutator may have upon its surface "flats" and "pits." In some of Edison's machines the brushes consist of many copper slips placed edgeways upon the cylinder. *Copper* is the material most in favour for brushes. It is usually as hard and pure as possible. The brushes themselves are easily kept in order, for being made of considerable length, to make up for wear, a fresh surface can always be obtained.

Insulating spaces of the commutator.—Many substances have been tried. Air gaps have been well tested. Gaps, however, unless kept clear by an air-blast, are apt to get clogged, so short-circuiting the segments. No insulating substance has proved so universally suitable as mica ("talc"). The secret of this material is to employ only such qualities as are pure and have a wearing capacity equal to that of good copper. If the mica does not wear down as fast as the copper the commutator will soon become useless. If, however, the mica easily grinds away, gaps will appear, which, filling with copper dust, will produce weakening of the dynamo and general break-down of its coils. A great deal of attention has been given to this point by many of the best makers of dynamos. Asbestos has also been extensively used, but not with such uniformly good results.

Lubrication of commutator.—Galling or attrition of the surface is speedily destructive of a commutator, as of any bearing in motion. Experience has shown that a lubricant must be used, and that *sparingly.* Ordinary oil and tallow was, until recently, in favour, but of late *vaseline* has been proving itself the least objectionable. The carbonising of ordinary oil and tallow frequently leads to partial short-circuiting. A well finished commutator in a good machine will, if well cared for, after a time acquire a glassy, hard surface, which needs very little attention.

Treatment of bad surface of commutator.—Superficial defects, as small rough spots, produced by burning, may be frequently removed by placing a slip of glass paper, or even fine emery cloth, against the revolving surface. A slip of emery cloth laid flat upon a smooth file forms a good corrector for grooving. A "dead smooth" file is probably the best of all. A commutator that is wearing rough should be seen to at once, otherwise it will go on from bad to worse. Re-turning is the best remedy for defects. As this usually necessitates the removal of the armature, it is not done so frequently as required. An ingenious engineer has devised a sort of make-shift slide-rest, for re-turning in position. The rest is bolted to the dynamo, and carries a tool in a suitable position for taking a cut off the commutator. This would appear to be an indispensable accompaniment of large dynamos. Brush-holders should be ot substantial construction and not liable to vibration. Many dynamos are very defective in this particular; it is indeed a matter of the utmost importance in the construction of these machines. The commutator and brushes necessarily form the chief care of a dynamo attendant, and some mechanical knowledge is indispensable to a man holding that position. Many attempts have been made to supersede brushes, by rolling contacts and other devices, but with indifferent success.

Short-circuiting.—A break-down of the insulation at any point, from the coil to the commutator bar, may produce short-circuiting and consequent loss of power. Carelessness in the management of the machine generally may speedily ruin its insulation. In inexperienced hands a dynamo may get put upon short circuit entirely and may even be "burnt-up" thereby. A dynamo should never be connected to an unknown resistance of moderate amount. In machines wound upon the shunt principle—when the exciting coils of the field-magnet are of high resistance, and form a by-path or alternative path for the current, the danger of being placed upon short circuit is not nearly so great. It would probably be impossible to "burn up" such a machine, because the proportion of current that could pass through the shunt would be so small that little or no magnetism would be produced, and consequently little current would be developed in the armature. On the other hand, accidental short-circuiting of a series-wound machine, or even a compound-wound machine, will be very likely to develop such a current as will speedily make its coils red-hot. The driving belt is liable in such cases to slip, through the abnormal load, and may thus save the machine. Of course, there is a limit to the magnetic strength of the field. The magnet may become saturated and may yet not produce a current sufficiently large to burn the machine; this may occur more especially in high tension machines. Testing for faults in the dynamo is quite an art in itself. A source of current and a sensitive galvanometer are required. Obvious contacts between coils, segments, and the body of the machine are easily found but not so readily located. As a galvanometer is generally useless near to a dynamo, the testing instrument should be kept at a suitable distance. Metallic dust from the commutator is a frequent source of short circuits in commutators and coils. Oil is another cause of trouble, when it falls upon the coils, and damp or water are equally troublesome. For these reasons hard lubricants only should be used, and machines kept in a dry place.

The following directions apply to the Brush and many other arc-lighting machines.

It will be found that when the brushes are rocked too far forward in the direction of rotation of the commutator, the sparks will quite disappear, but the lights will go out occasionally, and each extinction will be attended by a few long sparks on the commutator. This may be at once corrected by rocking the brushes in the opposite direction a short distance. If the brushes are rocked too far there will be much sparking and a diminution of light in the lamps, and occasionally extinctions will take place similar to those which occur when the brushes are rocked too far forward. The brushes should be rocked as far forward as possible without causing the occasional extinction of lights. When too much oil is used on the commutator, sparks will be produced similar to those which appear when the brushes are in the wrong position; hence due care must be taken to put only just sufficient to prevent cutting of the commutator segments. After the machine has been run awhile and has become warm, a slight re-adjustment of the brushes is sometimes advisable, and a little experience will soon enable the attendant to determine the exact adjustment that will produce the best effect.

When the brushes are much worn they must be clipped off squarely at the worn end, and moved up to the same position as before.

Driving.—When gas engines were first used for moving dynamos a good deal of trouble arose from the unsteadiness of the light produced. This is perhaps more noticeable in such engines as take gas by governor, once in three or four revolutions. A sudden acceleration of speed is thus produced when the impulse is given, which is manifest by a sudden brightening of the lamps. No remedy has been found so generally useful as the addition of a fly-wheel to the dynamo shaft. A driving band not too tight will thus yield somewhat at the moment of the impulse. Remarkable steadiness may thus be produced.

To ensure steady driving the motor should always have a considerable excess of power. This more especially applies to cases where great variations of load occur, as the sudden switching on or off of large numbers of lamps. Common steam engines fitted with old-style governors are most unsuitable for electric-light work. The automatic cut-off governor is coming into general favour, and great progress has of late been made in rendering the motor sufficiently sensitive.

Driving bands of leather are a source of much trouble when new. When long bands are used the stretching is considerable. The bands may be stretched by the makers to a great extent before placing upon the machine. The leather chain-belts, composed of short pieces of leather jointed with steel rods are less troublesome, give a better grip, are generally more flexible, and economise power better than solid leather bands. *Rope-driving* is coming into use in the case of large dynamos. This will probably be the method of the future in large work. It presents the great advantage of providing against the breaking or slipping off of the driving band and consequent stoppage. A large dynamo may in this way be driven by as many as ten ropes, running in separate grooves in engine and dynamo pulleys. *Chain-driving*, after the manner of tricycles, is frequently used for slow dynamos, and has been found to present many advantages. *Direct driving* has always been in great favour by both engineers and electricians. In this case the engine and dynamo shaft are simply coupled together in line. Direct driving is now used for large central station dynamos, and for small machines aboard ship.

Regulators of Current.

Many attempts have been made to invent or introduce some device by means of which currents from dynamo-electric machines might be automatically regulated or governed, as the steam supply is controlled in steam-engines.

The electric light without a steady current is very unsteady, and as constant strength of current depends in a great degree upon the motor itself, it is found that common steam-engines, unless of greater power than is really required, are not the best for the working of electric-light machines. In the earlier attempts at electric lighting there existed a want of perfection at three points concerned in the production of the electric light. The engine seldom had a sufficiently sensitive governor; the lamp was unsteady on account of various defects in the carbons; and the machine itself was entirely without a means of regulating its supply of current to the exigencies of the exterior portion of the circuit.

These faults combined did much to render the introduction of electric illumination difficult where a perfectly steady source of light was required. Staite and Edwards patented, so long ago as 1855, an electric regulator based upon the heating and expansion of metals by the current to be regulated. The metal used was platinum, in the form of wire; this was attached to a lever amplifying its movements, and the lever in turn moved a resisting coil of wire. This coil was a common naked helix, having some elasticity, and the action depended upon more or less turns of the wire being pressed together, so diminishing the resistance or augmenting it as the expansion and contraction of the platinum wire demanded. This idea, beautiful in itself, is really the origin of some of the regulators used at the present day.

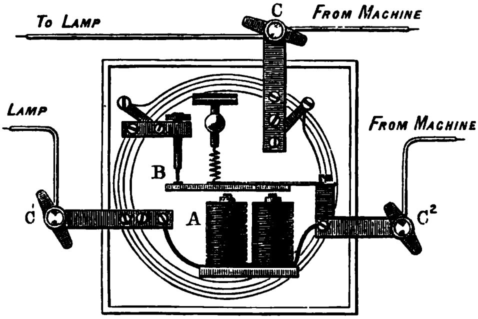


Fig. 92.—Siemens' "Circuit Regulator."

Dr. Siemens has constructed a regulator worked by the expansion and contraction of a strip of platinum or steel; but the apparatus, so far, does not appear to have been practically applied. The action is somewhat similar to that employed in Messrs. Staite and Edwards' device. The resistance coils used are put in or out of circuit by the amplified movements of a lever.

Siemens' Safety Regulator.—Fig. 92 is a view of the working parts of this regulator. It is issued by the makers of the Siemens machine.

A is an electro-magnet in the circuit of the machine and lamp; B is a contact point in connection with the main circuit through the resistance coil shown only. Normally, the electro-magnet attracts the armature, and the current passes right through the instrument without experiencing appreciable resistance; but should the lamp by any accident go out or break circuit, the machine cannot be damaged by the engine racing when the load is taken off. The resistance coil is equivalent to that of the lamp when burning, and to keep it cool it is immersed in a small tank of water in the base of the regulator.

It will at once be seen that this is far from being a regulator, in the true sense of the word, because it is only useful in the case of any *excessive* change in the current strength. It is, however, no doubt a valuable adjunct to the dynamo-electric machine, as much harm cannot be done to either engine or machine when this is in circuit. It is joined up in the usual way, by cutting the conductor near to the machine, and connecting one end to C, and the other to the same point, but, of course, on the opposite side of C, so that when the machine is working the current may pass direct to the lamp. The other connections C^1 and C^2, are made by cutting the remaining conductor, and joining up as shown. The instrument may be regulated for strong and weak currents by the antagonistic spring screw and by the contact screw.

In all regulating apparatus intended to regulate the current by actual breaking of the circuit, a very great objection is introduced by the extra current sparking at the contact. A word of explanation as to what this really is will not be unnecessary.

When two *short* wires are attached to any electric source, such as a voltaic battery, their ends touched and then separated, an exceedingly feeble spark only is noted; but when the wires are *long*, a large spark of great brilliancy is produced, and when the same wires are coiled up, especially around iron, the spark is still further increased in size and length. This is usually spoken of as the "extra" current spark, and is due to electro-magnetic induction.

Any regulator, then, depending upon actual breaking of circuit for its action, must so far be very inefficient, because no contact points yet discovered or tried will withstand the burning power of the electric spark.

Dr. Siemens also described, in January, 1879, a regulator based upon the curious property, discovered by Hughes and Edison, that carbon when under pressure will conduct better than when free from pressure. Thus Siemens proposed to place a number of carbon discs in an insulating tube, pass the current through them, and by means of a variable expansion of platinum, as in Staite and Edwards' apparatus, to vary, by more or less pressure, the conductivity of the carbon series.

Brush Regulator and Sensitive Relay.—A very efficient automatic regulator, based upon the property of carbon just mentioned, is used by the Brush Company. The construction is very simple. Two solenoids are placed in the field magnet circuit (it is notable that regulators are generally placed so as to control the field magnets only); projecting into these solenoids are the limbs of a U-shaped core of soft iron, which is attached and drawn more or less into the solenoids when the current is passing. This iron core is connected by a long rod of brass to a lever of the second order, the fulcrum of which is a short standard provided at the top with a knife-edge, on which one end of the lever rests. Near the fulcrum an adjustable screw, tapered to a point at the upper end, passes vertically through the lever, supporting a block which receives the weight of four parallel columns, each column consisting of a great number of thin plates of carbon, about 1 inch square. These columns are separated from each other by slabs of slate, but at the top and bottom are connected by small plates of carbon, which join the four columns in series. The action of the instrument will be readily understood. The carbon piles are connected as a shunt to the field magnet of the dynamo, and the solenoids are in the circuit of the machine. When no current is circulating in the solenoids the lever is not raised, and in this position of the lever the carbon piles are so separated that no current can pass that way. When the dynamo is working at full load the solenoids have not sufficient current to make connection in the carbon piles—in this position the full current circulates in the field magnet. But when several lamps are switched out, or the speed of the dynamo is allowed from any cause to increase, an increase of current takes place, and the cores are pulled farther into the solenoids, and the carbon plates are raised and brought into contact. Hence the carbon piles shunt off a portion of the field magnet current, and the strength of the field in the dynamo is thereby reduced until the normal current is again arrived at. When, on the other hand, the current given by the dynamo tends to weaken, the solenoids exert less pressure upon the carbon piles, and less current is shunted through them, so increasing the current through the field magnet.*

One of the great advantages of this regulator lies in the fact that it controls only a small current, and that little or no sparking is produced in its action.

The "Brush" Automatic Regulator has been improved by the addition of a relay adapted to it by Mr. Geipel. The relay consists of a sensitive core and solenoid arrangement, which responds more quickly to the variations of current than does the regulator alone. The control exercised over the regulator by the relay removes this defect. The relay has two contacts connected with the windings on the regulator coils. On an increase or decrease of current taking place the relay instantly weakens or strengthens the action of the regulator coils, and thus a prompt adjustment is obtained. There is a medium position of both relay and regulator which is maintained when the current has its proper value. It will be seen that this combination secures the separation of the part of the apparatus which requires to be powerful from the part which requires to be sensitive.

Recent advances in the application of the electric light would appear to indicate that by different methods of connection within the machine it may of itself become its own regulator.

The method employed at present is chiefly based upon the principle of exciting the field-magnets of the machine by a portion of the armature current only, instead of, as formerly, the whole of the cur-

---

* A full account of this regulator, with a diagram, is given in a supplement to the *Electrician* of Oct. 30, 1885.

rent. This principle was first published by Sir C. Wheatstone.* By these means a shunt-wound machine, as it is termed, becomes automatically powerful or feeble to meet the exigencies of the exterior resistance. This important method of exciting the field-magnets as applied to Siemens' machine, was published in a paper read by Mr. Alexander Siemens at the Society of Telegraph Engineers and of Electricians, in March, 1880. It is spoken of further on. This small current is easily controlled by various efficient regulators now in common use.

---

* "Phil. Trans. of the Royal Society," February 14, 1867.

CHAPTER VIII.

TRANSFORMERS AND ELECTRICITY METERS.

In the practical distribution of electrical currents for lighting it was soon found that to convey large currents at low potential to a distance, conductors so large as to be impracticable were required. On the other hand, although it was well known that small currents of high tension representing the same amount of energy could be conveyed easily in exceedingly small conductors, the principle could not be applied to ordinary lamps direct, and the introduction of such currents into dwellings would be a possible source of danger to life.

It has long been known that a low tension current could by suitable means be converted into a high tension current. The *induction coil*, an instrument for this purpose, is too well known to call for description. Its theory has been exhaustively treated in most text-books of electricity. The most powerful machine of this kind was owned by the late Mr. Spottiswoode, F.R.S. This coil would convert a low tension and harmless current into a high tension discharge, which would flash across an air-space 45 inches in width. Thus, from a current of a few volts, a conversion was made to a current of many million volts.

But the induction coil is reversible, for by feeding its secondary coil with a high tension alternating or interrupted current, a low tension current of great volume is obtainable from the primary coil.

Thus, the induction coil, which until within a few years ago was but a scientific toy, has developed into a most important auxiliary to the dynamo-electric machine.

In so far as the use of *transformers*, as they are generally called, has taken effect, they have only been successfully used for alternating currents. It is well known that if a constant current be passed through the primary wire of an induction coil the secondary circuit will evince no sign of current. At the moment of making or breaking contact with the primary coil, however, momentary currents will flow in the secondary coil. Hence the necessity to use a contact breaker or interrupter with such coils.

But if a constant current flows in the primary coil, and that coil be moved within the secondary coil, currents corresponding to the motions will be induced in the secondary—in fact, we have now a kind of dynamo machine. Hence, if the current transformer can be used for converting constant currents of high force to constant currents of low force, they must take the form of machines of some kind.

Transformers are chiefly used, first, for *augmenting* the electro-motive force of the currents produced by the dynamo, so that these currents may be carried by small and inexpensive conductors. Such currents, as we have seen, cannot safely be allowed to enter ordinary dwellings, and the transformer comes again into play—this time to *reduce* the electro-motive force to a safe limit.

Thus, a dynamo may work at 100 volts, and produce a very large current. That current, if it is to be carried to a distance without conversion, might need a conductor of great thickness—it might be a copper rod an inch in diameter—the cost of which would be prohibitive. But we must get the current delivered at the distant point at the potential of 100 volts. A transformer is therefore brought to bear at the dynamo, which converts the large current of 100 volts to a small current of 1000 volts. This current might then be conveyed to the distant point in a conductor, say $\frac{1}{8}$ of an inch in diameter. Another transformer then comes into play, and reduces the potential and augments the current to the original value, less a certain loss in the conversion.

But it is far more common to construct dynamos yielding potentials sufficiently high for transmission direct than to use transformers at the dynamo end of the line, although it will probably be found that low potential dynamos are less liable to break down than those furnishing currents of 1000 volts or more.

Secondary or Storage Batteries as Transformers.— The use of these has been strongly advocated. Thus, if a storage battery be set up in series it may be fed by a high tension current. It may then be disconnected and so arranged in parallel arc as to yield any potential, from that of the charging current to that of one cell only.

Professor Faraday's experiments in 1831 led him to produce the first induction coil, which proves the parent of all subsequent forms of transformer based upon magnetic induction.*

This consisted of an iron ring, six inches in diameter

---

* "Experimental Researches," i. 7, 1831. "Philosophical Transactions of the Royal Society," 1831.

and about an inch thick. Upon one diameter of this was wound a primary wire about 72 feet in length, and upon the opposite diameter a secondary wire 60 feet in length. By connecting the primary wire with a battery and the secondary with a galvanometer, strong momentary currents were induced in the secondary coil at each make and break of contact with the battery.

All subsequent improvements upon this form of transformer have had for their object a greater efficiency and less loss of energy in heating the iron core.

If both the wires be of the same size, and if they take an equal *number of turns* around the core, it is assumed that the potential of the secondary will equal that of the primary. If the secondary takes a greater number of turns than the primary, the potential of that circuit will be augmented. When a very high potential is to be used the secondary is made from fine wire, giving a large number of turns in comparison with the small number of turns made by the larger primary wire.

Conversely, if the currents are to be reduced from a high to a low potential, the secondary wire is no longer the fine wire; the latter then becomes the primary, and carries the main currents, while the short, thick wire becomes the secondary, and yields currents of low tension.

Hence the manipulation of the current for any specific purpose becomes a comparatively easy matter by the aid of this apparatus.

The chief improvements that have been effected in the induction coil or transformer were mostly all due to experiments made long before electric lighting became practicable. The merit of subdividing the core, so as to eliminate useless eddy currents and consequent heating is due to Masson (1837). The introduction of the induction coil for distributing currents for electric lighting is claimed by several, among whom Jablochkoff (1877), Bright (1878), Edwards and Normandy (1878), Marcel Deprez and Carpentier (1881), Edison (1882), Lane-Fox (1883), and later, Gaulard and Gibbs, Kennedy, Deri and Zipernowsky, Ferranti, Westinghouse, Kapp, Snell, Mordey, Statter, etc.*

The fundamental disposition of the parts in a transformer were well understood long before such an instrument was thought of in connection with the electric light—they are, briefly, a closed magnetic circuit, dating from 1831, and a core carefully laminated or subdivided, dating from 1837. The development of the instrument to its present efficiency has been exceptionally rapid.

Zipernowsky's Transformer.—This has been made in two forms; the first merely being a development of Faraday's famous ring. It consists of a ring of soft iron wires, upon which are placed ten or more distinct coils. Five alternate coils are connected together, forming the primary wire, and five alternate coils similarly joined forming the secondary circuit. Whichever wire is to carry the higher electro-motive force is made the finer. In the second construction of Zipernowski's transformer, the coils of wire are arranged so as to take the place of the core; they form, in fact, the "ring." Thus, two rings formed from the primary and secondary coils being coiled up in that shape are placed one upon the other, their centres coinciding. The "core" of iron wire is then wound upon them, taking the place of the coils in the first

---

* See list of Transformer Patents, p. 205.

form of the transformer. Thus, the induction coils become the core, while the latter, as used by Faraday, becomes the encircling coil. This iron wire is wound on with a shuttle—the arrangement might be termed a transformer with an external "core." The main point aimed at by inventors is to form two closed links, linking them together. Fig. 93 shows the arrangement.

Messrs. Gaulard and Gibbs for several years used the ordinary induction coil form, consisting of a straight iron core, with primary and secondary wound upon it, forming the well-known "bobbin," or "reel" shape. The power of these transformers was regulated by various arrangements for withdrawing more or less of the core. They were usually set up vertically, and in sets of four or more.

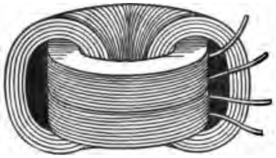


Fig. 93.
Zipernowsky's Transformer.

The construction of transformers is continually being varied, necessarily from the nature of the instrument, and improvements are being made in each form from year to year. But the tendency at the present time is undoubtedly in the direction of employing large numbers of rectangular stampings from soft sheet iron, and so forming boxes or "shells" for the reception of the coils. It is found that if the coils be not only filled with soft iron but also surrounded and enclosed in it, the efficiency of the transformer is correspondingly increased. In all cases the iron employed must be subdivided, or laminated, so as to prevent heating and loss of current.

Messrs. Kapp and Snell arrange the "shell" portion of their transformer as represented in Fig. 94, where are shown two sets of U-shaped stampings from sheet iron placed side by side, and forming a square core, through which run two oblong chambers to receive the coils of wire. The stampings removed from the sides to form the U shape are used, as shown, set upon edge, to complete the magnetic circuit. The stampings in this transformer are of the following dimensions:—5 in. high and 3½ in. broad.

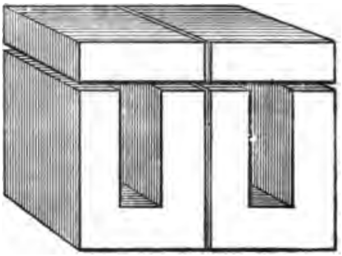


Fig. 94.—Kapp and Snell's Transformer.

Kennedy's transformer, as used for raising the potential in the mains at a generating station, is shown in Fig. 95. In this case the stampings are not only made to envelop the coils, but pass through them also. Each pair of plates is thus separated by a cross strip. Each chamber contains a primary and a secondary coil.

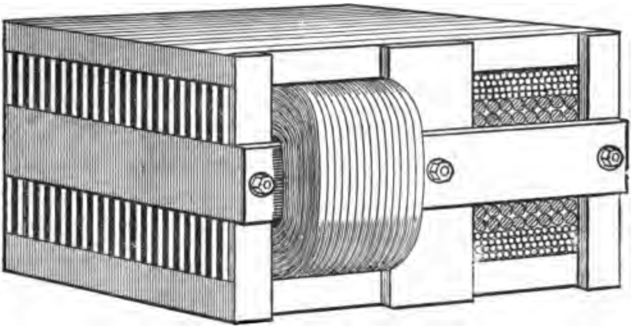


Fig. 95.—Kennedy's Transformer.

Transformers self-regulating.—It is a peculiar circumstance that the transformer has the property of self-regulation to the requirements of the secondary circuit when connected in parallel with the mains. Thus, if a transformer be loaded with 100 lamps, and it feeds these as desired, if 50 of the lamps be turned off, the current flowing in the primary will fall 50 per cent. And if the remaining lamps be switched off, little or no current will flow in the primary, although the pressure in the mains is constant. The explanation has been sought successfully in the "damming back" effect of a counter electro-motive force induced in the primary by the iron of the transformer. But while the transformer exhibits this property to a remarkable degree, an ordinary induction coil does not evince it to anything like the same extent.

Since the use of transformers is comparatively recent, it is impossible yet to say which is the best system upon which to use them. It is generally agreed, however, that to supply a small transformer for each lamp is unnecessary. The present practice is to fix a transformer capable of taking a sufficiency of current for the whole of a building just outside its walls, so as to keep the high tension of the mains without. In America, where it is a general practice to lead the mains along the pavements upon poles, a transformer is fixed upon a pole opposite each building to be supplied with current. This system is extensively used by the Westinghouse Company in the United States, the tension of their mains being 1,000 volts, and that of the lamp circuits 50 volts, or as 20 to 1.

The following dimensions are given for a transformer capable of transforming a current of 1·5 ampère at 1,000 volts down to a current of 37·5 ampères at 40 volts: total external size 20 × 6 × 4 inches. Primary wire, 5 lbs., 0·035 inch diameter; secondary, 5½ lbs., 0·12 inch, 25 in parallel; weight of iron about 50 lbs. Efficiency—this is said to be 97·2 per cent., but no particulars are given as to the current flowing.

Electricity Supply Meters.

Considerable progress has been made in the development of meters for the accurate registration of a supply of electricity, either for lighting or motive power. The question is of so much importance that it is probable that already every known means of obtaining accurate results has been carefully tested.

Some of the meters are extremely ingenious. Perfection has certainly not yet been attained, but it may be safely said that a good electricity meter may easily be made as accurate in its readings as an average gas meter—the accuracy of which is more often a matter of speculation than of fact. The current meters may be briefly divided into two great branches—those for continuous currents, as for Edison's system, and those for alternating currents, as the Ferranti system. They depend either upon electrolysis or electro-mechanical action for their indications.

Meters intended to register by electrolytic action were probably first used by Edison. The principle, and even its application to practical purposes of electrical measurement, were both, however, very well known twenty years ago, and Mr. J. T. Sprague suggested such a meter before the year 1875.*

Edison's meter for continuous currents consists of a pair of zinc plates, kept a little apart, and plunged in a solution of zinc sulphate. Any current passed through this cell will abstract from the entering plate and add to the emerging plate—that is, the anode plate will dissolve, and the cathode plate will receive the metal so dissolved. The amount of zinc so transferred is accurately (or nearly so) proportional to the current

---

* "Electricity; its Theory," &c., London, 1874.

that has passed through the cell. This is a well-known fact of electro-metallurgy. The principle may be more fully studied in the author's "Handbook of Electrotyping."

In addition to the electrolytic cell the meter consists of a shunt arrangement, by means of which about $\frac{999}{1000}$ of the current supplied passes by the meter, only $\frac{1}{1000}$ passing between the plates. Such a meter is placed between the electric mains and the lamp circuits of the house to be supplied. Before the meter is attached its plates are weighed. They are weighed again at the end of every month. The loss in zinc by the anode plate will then indicate the quantity of electricity that has passed, and the customer is rated accordingly.

To render the meter accurate some means must be devised to compensate for the variations in conductivity of the electrolytic cell, due to changes of temperature. A rise in temperature is followed by a diminution of the resistance, and an increased current would flow through the meter, and *vice versâ.* The resistance of copper, on the other hand, increases with a rise of temperature, and the proportion is so nearly the same that a little copper coil, placed in the circuit of the cell, serves to compensate for any variations, the one balancing the other very accurately.

Fig. 96 shows diagrammatically the arrangement. The density of the solution in which the zinc plates z z are immersed is maintained at about 1·054, and the plates being about $\frac{1}{4}$ inch apart, the resistance of the cell is nearly 1·75 ohm. The balancing copper coil *a* is 8 ohms, *b* is a resistance of German silver, in the form of a zig-zag. The meter merely forms a by-path or shunt to the course of the current as it enters the house. In fact, most meters must necessarily be arranged in this way if they present any appreciable resistance. When a large current is to be supplied the meter has two, and sometimes four cells. An incandescent lamp is usually fixed in the meter case, and during the winter months this is kept lighted, which prevents the solution from freezing. It has been pointed out that this system leaves the adjustment of the accounts entirely without check in the hands of the electric company, but it is said that no complaints have so far been made against it.

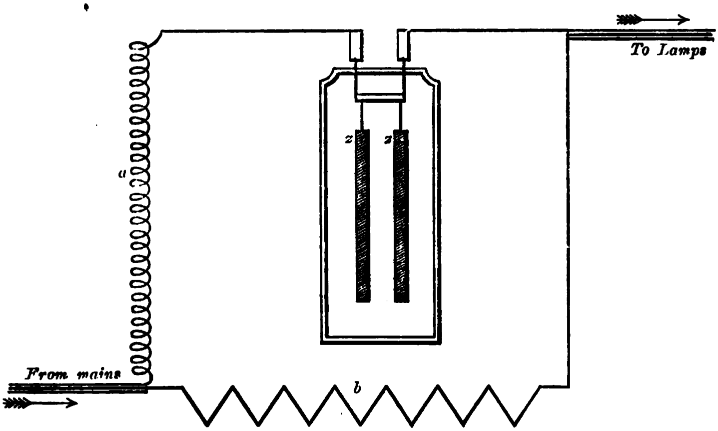


Fig. 96.—Edison's Electricity Meter.

Schallenberger's meter is used chiefly by the Westinghouse Electric Company, and has done good work in America. It is intended for the registration of alternating currents. This instrument is a remarkable example of the utilisation of electrical principles for a practical purpose. It consists essentially of an iron disc, placed in a horizontal position, and capable of rotation upon a vertical axis. A rectangular coil of wire, placed horizontally, surrounds the disc, leaving space between the two. This coil carries the current to be measured. A second coil of wire, within the first, also surrounds the disc, but does not touch it. This coil is a complete circuit in itself, *and is inclined at an angle of forty-five degrees to the current-bearing coil.* The secondary coil is in fact a self-circuited induction coil. The object to be obtained is the rotation of the iron disc. When a positive current flows in the current-bearing coil it creates a magnetic polarity in the iron disc. It also induces an opposite current in the secondary coil. But the "phase" or life of the positive current will have ebbed away before the secondary negative current has attained its maximum—that is, the induced current will be *half a phase later* than the principal current. The secondary current then tends to give motion to the iron disc by attracting the pole previously created by the principal current. Again, the principal current passes, but the impulse is negative, and a fresh pole is created in the iron disc, while a positive current is induced in the secondary coil, which again attains a maximum as the negative current reaches zero. Again the iron disc is attracted and moved forward in the same direction—so a continuous rotation is kept up simply by virtue of the electric lag of induction between the coils.

We have here, in fact, an electro-motor capable of being actuated by alternating currents, and this principle indeed forms the basis of *alternating current motors*, in so far as the invention of such machines has progressed.

In the Schallenberger meter the rotation of the iron disc is utilised to set a train of wheels, carrying indices, in motion, and these indicate directly the quantity of electricity used. The upper extremity of the axis is utilised for this purpose, while the lower end carries a fan to prevent over-running or too free a motion. It has been contended that meters of this class must be subject to variation with variation of phase in the alternations; in other words, the speed of the dynamo would upset the reading of the meter. This may be true within narrow limits, but no such serious difficulty has been experienced by the Westinghouse Company in America.

Ferranti's Meter.—Here we have another beautiful example of an electrical phenomenon utilised for a practical purpose. It is based upon the principle that when an electric current flows through a fluid body which occupies a magnetic field, the fluid has a motion perpendicular to the current and to the magnetic field.

The instrument mainly consists of a tubular electro-magnet consisting of a hollow iron core, over which an exciting coil is wound, and an exterior casing of iron. We have thus two tubes, one within the other; the upper end carries a yoke piece as usual. The lower extremities form the poles, the outer one being the longer, and carrying an extension ring, which leaves an annular chamber in which is placed a quantity of mercury. The mercury thus occupies a magnetic field, the lines of which are vertical lines. The current is made to pass through the mercury from centre to periphery, the result being its continuous rotation in one direction. This motion is taken advantage of by means of a fly or float, moving with the mercury, and attached to a vertical axis, the upper end of which sets a counting train in motion in the usual way. Many inventors have endeavoured to utilise the rotation of mercury in a magnetic field for the purpose of measurement, but difficulties have always sprung up in the shape of the gradual oxidation of the mercury. Mr. Ferranti claims that by means of extra purification he has eliminated this fault. But it might be possible to work such a meter in a constant vacuum, so preventing oxidation of the mercury.

Forbes's Meter.—Professor Forbes relies upon convection currents in the air arising from a conductor heated by the current. The instrument consists of a horizontal ring of wire having a resistance of $\frac{1}{100}$ of an ohm. Motion is given to a kind of exceedingly light "windmill," also placed horizontally just over the conductor. The axis of the windmill is utilised to move the counting mechanism. This kind of meter has the advantage of being available either for measuring direct or alternating currents.

Clock Meters.—These are now very numerous. One of the best known is that first suggested by Messrs. Ayrton and Perry, and brought out by Dr. Aron, in Berlin, where it has been in successful use in connection with the large central station there. In its modified form it consists of two clocks, the pendulum of one of which is so influenced by a current-bearing coil that its rate is retarded. The retardation is assumed to be proportional to the current passing in the coil. The amount of the retardation is got by comparing this clock with the standard uninfluenced clock. But lately a differential gear has been put between the trains, which enables the amount used to be read off at once from the dials. The only difference between the clock meters for direct and alternating currents consists in substituting for the ordinary metallic pendulum bob used for direct current a coil of wire, moving in an enveloping coil used for alternating currents. The clocks are sprung to go for six weeks with one winding, while the readings are supposed to be taken once a month.

It is a much more difficult problem to produce a satisfactory meter than is generally supposed. Many points require careful consideration. The chief of these are, no doubt, *accuracy* and *range* of working. Most meters are only reliable within a narrow range. Another point of greatest importance is a capability to check the voltage at work in the circuit. It is notorious that the voltage may be diminished without corresponding diminution in the chargeable value of electricity supplied.

Patents for Induction Transformers.—Jablochkoff, No. 1,996 of 1887. Bright, No. 4,212 of 1878. Edwards and Normandy, No. 4,611 of 1878. Deprez and Carpentier, No. 4,128 of 1881. Edison, Nos. 3,752 and 3,949 of 1882. Lane-Fox, No. 3,692 of 1883. Gaulard and Gibbs, No. 4,362 of 1882. Deri and Zipernowsky, Nos. 3,379 and 5,201 of 1885. Ferranti, No. 15,251 of 1885.

CHAPTER IX.

ARC AND INCANDESCENT LAMPS.

AN electric lamp is the apparatus at which the electric current is actually converted into light. Generally it consists of an arrangement of two carbons for forming the electric arc between them. But the property of the electric current, by which it heats any highly resisting portion of the circuit, has been utilised in the production of a lamp in which a filament of carbon is heated to whiteness, which has been so successful that these incandescence lamps are coming into general use for both interior and exterior lighting.

Arc Lamps.—When two pointed sticks of carbon attached to the two poles of a source of electricity, such as any of those previously described, are touched together, a current will pass, and the carbons may then be separated a certain distance without interrupting the current, which is carried on by the intermediate air heated by the current, and an exceedingly brilliant light, which is termed the *voltaic arc*, will be produced between the carbons.

Particles of burning carbon are projected from one carbon to the other and a portion of the light is attributed to this flow of burning matter, but the greater portion is due to the incandescence of the carbon, or to a conversion of electric current into light, as inexplicable as that produced in a spark discharged between two conductors, or in a flash of lightning. The researches of Capt. Abney, R.E., F.R.S., have shown that while the white light of the positive pole is always of the same composition in respect of the relative proportions of waves of different colours, the temperature of the arc from graphite carbon is also the same in arcs of different powers—the temperature of fusing graphite.

The positive carbon, or that *from* which the current is generally assumed to flow, is, in voltaic arc lamps, consumed very fast, and becomes hollowed out, forming a crater, while the negative or receiving carbon is acted upon very slightly, and becomes pointed. Carbon rods may burn at the rate of about 5 in. per hour, according to their size, and as they consume away must be fed up to each other in order to continue the light. This was formerly done by hand, but now it is effected by such perfect automatic lamps that the light is not only perfectly steady, but needs no attention whatever for several hours together. It is no difficult matter to feed carbons by hand, by means of a screw attached to one of the pencils, and for taking photographs by quick-acting plates this will answer very well, but a lamp is the only satisfactory means by which ordinary carbon rods can be burned for general purposes.

In another class of lamps the carbons are kept actually in contact. Thus, if pointed rods of carbon, or one pointed and one flat carbon or piece of copper, are attached to the poles of a source of electricity, and the two poles are brought together, a bright light will be produced at the point of actual contact, and will remain practically steady as long as the carbons are kept together. This principle is adopted in several different kinds of lamps. The light is partly due to the incandescence of the carbon and partly to the voltaic arc produced round the point of contact. These devices are sometimes spoken of as "*semi-incandescent* lamps."

Such lights are not so brilliant as those produced when the carbon pencils are actually separated.

As early as 1843 experimenters were at work upon this useful application of electricity, and the celebrated Foucault produced the light from rods of gas carbon and a battery of Bunsen cells. Previously to this wood carbon was frequently used, and among others by Sir Humphrey Davy, at the beginning of the present century, when he produced his (and the first) voltaic arc over the Royal Institution, from a battery of 2,000 cells (page 2).

Fig. 97.
Carbon Points.

It was soon found that the electric light was not only independent of air or oxygen for support, but possessed the properties of sun-light in showing all colours as they appear to the eye in sun-light. It was also found that no vapours, smoke, or appreciable (diffused) heat were given off by it, and that its chief peculiarity was exceeding brilliancy difficult of diffusion.

Fig. 97 is an enlarged view of the carbon points as they actually appear when their image is thrown upon a screen for examination. P is the positive or feeding end, and N the negative or receiving. The nodules observed chiefly on the lower carbon are impurities in the substance, which melt and stick to the points. The light itself is not only produced by electricity itself, but by millions of highly incandescent particles carried from the positive to the negative carbon.

The stronger the current under these conditions the more powerful the arc, and the greater distance will the carbons admit of being separated without extinguishing the light.

The power of electric light is usually expressed in terms of the standard candle, and varies from, say, 10 candle power to 16,000, above which it has not as yet been found generally economical to go in one centre of light.

It would appear that about the year 1845 the first patents were applied for in electric lamps or burners. The names of King and Wright are the first concerned in the invention of patented apparatus of this kind. King's patent was for an incandescent burner of platinum, and Wright used revolving discs of carbon. Probably the best attempt at obtaining a steady light shortly after this date (1846) was that of Staite and Edwards, who made a lamp in which two rods of carbon were pressed together at an angle upon some badly conducting substance. Greener, Staite, and Petrie then produced lamps of various kinds, and in 1848 a self-regulating lamp was made by Foucault.

It will be unnecessary to give particulars of all the numerous, and often useless, pieces of electric lamp apparatus invented since 1845; we shall therefore describe only those lamps which have of late years been most extensively used, or are otherwise of practical interest.

Carbons.

As has been before stated, rods of charcoal were first employed as the points in the production of electric light. This was found to burn too fast, and is too easily split, although, when well prepared, it may be used for experimental purposes.

The scale of deposit found in the interior of gas-retorts after use was found to be well adapted for the purpose. This substance is inexpensive, as it may usually be obtained for the trouble of carrying away; but it is not, in its crude state, well suited to the production of steady light. It is very impure, containing various foreign earthy matters, sometimes metals; but silica is the most troublesome constituent, as it is more difficult of fusion than the pure graphite. A good gas carbon is of a fine texture, and a clear grey colour. It is very difficult to cut or shape, on account of its hardness.

Many attempts have been made since 1846 to obtain a perfectly pure powder of graphite or other substance suited to the steady production of light.

Staite and Edwards' Carbons.—These were in use for a considerable time before other inventors came into the field. They were made by finely powdering the best gas carbon, mixing with a little sugar syrup, kneading and compressing in the shape of rods. They were then gently heated and saturated with a strong solution of sugar; they were then heated to whiteness, and were found to burn with tolerable uniformity in good lamps. The same method, with the substitution of tar for the syrup, and the addition of ground charcoal, was patented by Le Molt a few years later.

Archereau's Method consists of mixing with the ground and selected graphite some magnesia, which is supposed to render the light more steady. But it has been found that the addition of any substance more readily fusible than graphite invariably lowers the temperature of the arc and its consequent brilliancy.

Carré's Carbons.—These were for many years the standard carbon rods in use. He mixes with the substance certain proportions of potash and soda, which slightly lengthen the arc and are said to add to its brilliancy. Good carbons are made from the powdered carbon, lamp-black, and syrup of cane-sugar, with a little gum. The proportions may vary, but the following are recommended;—Carbon powder, 15 parts; calcined lamp-black, 5; syrup, 7. These substances are perfectly mixed, with a very little water added, when the mass is well pressed and rounded by being passed through a draw-plate. The rods are then baked dry, and while still hot are immersed in a solution of cane-sugar or a strong syrup, which is pressed into their pores, and they are then again heated to a high temperature. Carré would appear to prefer coke-dust, as found in retorts, to ground carbon.

Many attempts have been made to improve the conducting power and steadiness of carbons by coating them with metals. They are almost all failures, except the method of coating with copper, which at least has the merit of diminishing the resistance of the carbon rod. Lamps are now in use by which the current is not caused to travel the whole length of the carbon. A great many mixtures have been tried both inside and outside the carbons. Several varieties of tubular carbons are in use, while the very large carbons used in lighthouses and for war signalling are usually of a fluted or pinion-form externally.

Carbon rods frequently crack and split at the points, so extinguishing the light for an instant. This usually results from the use of inferior materials, and by employing rods of too small a body for the current. Carbons should be selected to suit the current to be passed through them. If they are irregular in composition they will crack, and whether regular or not they will crack when the current is too strong for their size. M. Gramme mixes with the powders nitrate of bismuth, which is of use in preventing cracking and augmenting the steadiness of the light.

In arc lighting it is important to observe that the arc should be maintained as large as the electromotive force of the electric source will permit. The length of the arc may vary from 1 millimètre (about the $\frac{1}{25}$th part of an inch) to several millimètres. When the arc is too long, the light will become of an uncertain and flaming nature, and may be easily extinguished by any diminution in the current strength. When the arc is too short, the light produced will be only partially diffused, and may be quite shut in upon every side by "mushrooms," or excrescences around the points, particularly the positive point. The hissing noise made by the arc generally indicates the presence of impure carbon, or too short an arc. The carbon rods should be as large as the current from the electric machine will easily consume. If the rods are too thick, only a portion will be consumed at once, and not the whole sectional area of the rods. If the positive carbon should burn into several craters, it is too large. If the carbons are too thin, they will be unduly heated throughout their length, and will offer great resistance.

Lamps with Automatic Regulators for Arc.

When the electric light is obtained by carbons separated a certain distance so as to produce the voltaic arc, the carbons consume away, and thus increase the length and electric resistance of the column of heated air between them. As the resistance increases, the current diminishes; this decrease of current again lessens the heat of the column of air which has already been lengthened, thus the rapid increase of resistance soon causes the arc to cease altogether suddenly. To overcome this the carbons must be kept constantly at the same distance apart.

In 1846 Staite used clockwork to bring the carbons together, the rate of the clock being previously regulated to suit approximately the consumption of the carbons, but this was not found to answer, as the carbons burned irregularly.

Attempts to make the decrease of current itself adjust the carbons were soon made. It is difficult to give the date of the earliest invention for this purpose, but Staite as early as 1847 patented a lamp in which the clockwork for moving the lower carbon is controlled by a movable weighted soft iron core acted on by a hollow electro-magnet.

Probably the Foucault and Wilson lamps were the earliest. We cannot, however, pretend to place the various lamps in chronological order, but commence with the Serrin lamp, as a good type of the clockwork or self-regulating kind.

Actuating Devices for Arc Lamps.

The devices resorted to by inventors are of various kinds, some of them extremely ingenious. The subject divides itself into two main branches: arc-forming or "striking" devices, and "feeding" mechanism or driving power. The most generally used method for "striking" the arc was embodied in Staite's patent of 1847, and consists of an electro-magnet having its coils in the lamp circuit. In later forms a solenoid or "sucker coil," provided with a movable core in contact with the carbon to be moved, is very largely used. In some forms of lamp, however, the carbon points are continually kept apart save at the instant of "striking" the arc. The most generally favoured method of effecting this consists of a solenoid of fine wire forming a by-path or shunt to the lamp circuit. This has its movable core connected to the carbons, or one carbon, so that when the current passes in the solenoid its attraction shall "strike" the arc by bringing the carbons together. As soon, however, as the circuit of the lamp itself is thus closed, the solenoid necessarily loses power by little or none of the current passing that way (according to the law of resistances), and the arc is opened to the required degree.

Feeding Devices.—These are extremely numerous. The great majority of lamps depend upon gravity for feeding, and in some cases for "striking" the arc also. The upper carbon-holder either descends by its own weight (Serrin's lamp, 1859) or separate weights are employed for the same purpose. Clockwork is also much used, generally under the control of the current; springs of various kinds, as in Foucault's lamp of 1848; electro-motors, consisting of rotating armature or vibrating lever, and (far more commonly used) solenoids, with parallel or double or single taper movable cores, balanced with the carbon-rod, as in the Pilsen lamp (1888).

The Serrin Lamp.

Fig. 98 is a view of the interior of this lamp. A is an electro-magnet; B its armature, which, when the current passes, is attracted, and through its connection with the sliding bar of the lower carbon, E, pulls it down, and makes the separation. The apparatus is put in motion, not by a spring, but by the weight of the upper carbon holder constantly tending downwards, which pressure communicates motion to the train of wheels by its toothed rack, as

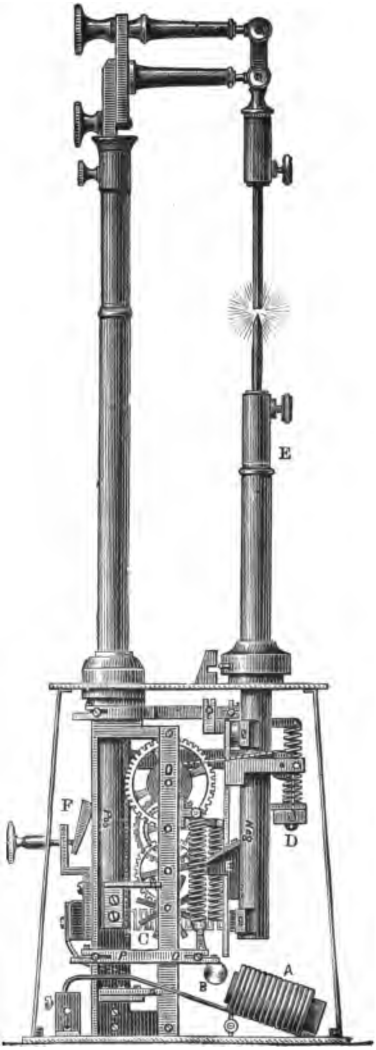


Fig. 98.—Serrin's Lamp.

shown. The rate of descent in the upper carbon with its rack is, of course, regulated by its setting the wheel train in motion, which brings a detent, E connected to the left side of the lower carbon holder, to bear upon the arms of the radial fly-wheel lowest in the train of wheels. This locks the length of the arc until from burning away the current becomes weak, and the armature is allowed to go upwards with its lower carbon holder. This it is enabled to do by the springs constantly pulling it away from the magnet. When the lower carbon is thus free to move upwards, the upper, its wheel train being free, by the check being taken off the radial fly, falls until the current is strong enough to again pull down the lower holder and to again bring the check to bear upon the radial fly, thus locking the distance. F is an adjusting screw, and the two upper screws are for the same purpose. This lamp is singularly efficient, and may be set in action by the most ordinary workman.

Archereau's Lamp.

Fig. 99 represents a lamp invented by M. Archereau. It is very simple in construction and action, and forms one of the best regulators for short periods in use, and is therefore recommended to amateurs for experimental purposes.

PRACTICAL DIRECTIONS.

It consists of a bobbin or solenoid of No. 12 silk-covered wire, composed of one layer, or two at most, for weak currents, A; having within it a column of metal, B. This cylinder is of soft iron. Its upper end, B, carries the lower carbon-rod, which is fastened by the set screw shown. The connection to this coil of wire is from the binding-screw to one extremity, while the other end of the coil has soldered to it a thin copper spring, pressing gently upon the interior column. The current thus passes to the lower carbon, while the other connection is made to the metallic upright at D. This metallic pillar may be of brass, and carries a right-angle arm, to which the upper carbon holder is attached, as represented. A counterpoise weight, C, is supported by a cord, which leads over the central pulley, and, passing under the lower extremity of the metallic column in the wire coil, supports it in position, with a gentle pressure between the carbon points.

The connection with the electric source being made, the solenoid magnetises B, which is attracted into the coil. The action is as follows:—The current passes into the coil, up through the carbons, and at once separates them. If the separation has been too sudden or far, the weight will bring the points nearer to each other again. The arc is established as soon as the current passes, and the weight should so counterbalance the column that its action may not be too strong for the current. It will be found best to have the counterpoise adjustable.

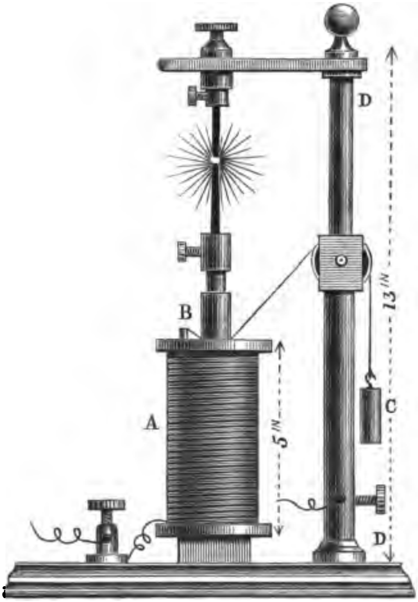


Fig. 99—Archereau's Lamp.

Fig. 100 represents a coil and bobbin of wirefor thislamp, having within it the iron column, with the carbon-rod fixed in the top. For a lamp to burn, say, for 1½ hours, with a light of 500 candles, the wire may be No. 12, and it should be silk-covered.

The bobbin should be of hard wood, with a thin tube. It may be 5 inches long, and the central chamber may be $\frac{3}{4}$-in. in diameter, while the diameter of the sliding column may be $\frac{1}{2}$-in. or even less. The total length of the column may be 7 inches, and it should be provided with a brass or iron socket, having a $\frac{3}{8}$-in. hole in its end for the reception of carbons of different sizes.

The total height of the lamp may be 13 inches, and the cord pulley must be placed above the middle portion of the main pillar, as represented, in a slot cast or cut for it. It will be found convenient to have the right-angle arm adjustable around the main pillar as an axis by a thumb-screw; and it is useful to have the top carbon screw or socket drilled right through, so that the carbons may be pushed downwards, from the upper side.

The base must be solid and firm. It will be found best in most cases to provide one of cast-iron, and to insulate the binding-screw from it by fastening a block of wood in a $\frac{1}{2}$-in. hole cast in the base.

Of carbons, the size will depend altogether upon the strength of current to be used in the production of the light. This lamp is very well suited to the current as obtained from voltaic batteries, and it will prove useful to give sizes of carbons best suited to different strengths of such currents.

A current from 50 cells of the Bunsen, or 40 of the bichromate of potash cells, will consume from $\frac{1}{4}$ to $\frac{5}{16}$-in. carbon rods, and if the cells are large the carbons may be ordinary $\frac{3}{8}$ rods; for smaller numbers of cells the $\frac{1}{4}$-in. rods will be found quite large enough. Round rods are better in work than square rods. They should be pointed on commencing the light.

Fig. 100.—Bobbin for Archereau's Lamp.

Brockie-Pell Lamp.

This has proved itself one of the most successful of modern arc-lamps. It is controlled by means of both shunt and series solenoids with movable cores.

Fig. 101 exhibits in outline the main features of the active parts of this lamp. These consist of a pair of solenoids, one of which is in the circuit of the lamp and the other acting as a shunt, and wound with fine wire. The solenoids, $a\,a^1$, have movable plungers, which are in turn connected to a vibrating beam, *b*, pivoted at *c*. The main novelty lies, however, in the large brake-wheel, carrying a pinion, *d*, gearing into a rack cut in the upper carbon-rod, *e*. The weight of the carbon-rod causes the pinion and brake-wheel to revolve, but the movement of this is checked by an internal brake arrangement acting upon an interior flange of the wheel. The brake or nipper-lever, *f*, is pivoted at that point to a quadrant piece moving

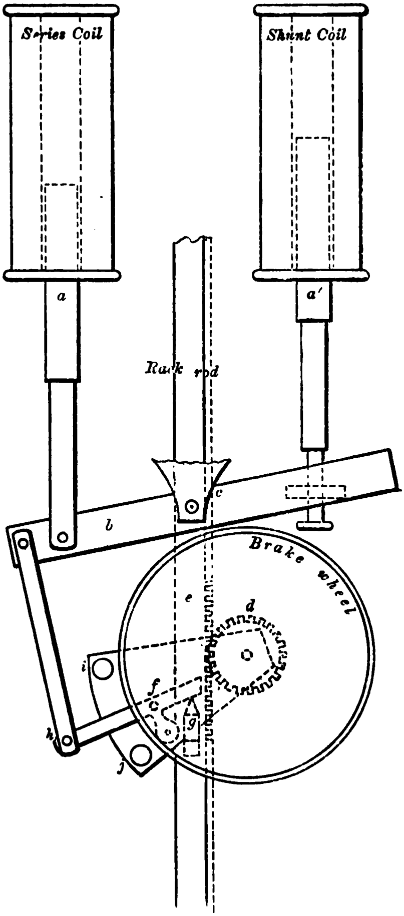


Fig. 101.—Brockie-Pell Lamp-Action.

independently upon the same centre as the pinion, the little leather-covered roller depending from the nipper-lever forming the brake proper. The lever is jointed to the overhead-beam, *b*, and so is under the control of the series coil. A stop, *g*, is provided to limit the movement in that direction.

It will be observed that, supposing the carbons to be in actual contact and the current were passed, the series solenoid would draw up its core along with the lever and brake-arm, so locking wheel and brake together. A still further pull of the solenoid will strike the arc by a movement of wheel, pinion, and rack. When the arc becomes abnormally long, the current in the solenoid will be weakened, and the brake-lever will gradually slip back out of contact, and allow the rack to rotate pinion and wheel in its descent, when the re-establishment of the normal arc gives the solenoid its proper strength to retain its hold or re-lock the wheel.

The quadrant-piece carries two little weights, *i* and *i*. Such a lamp, having both shunt and series coils, can be used either in series with other lamps or in the parallel system of distribution, in which the lamps merely bridge across the mains, either singly or in series of two or three. In the former case (series working) the shunt coil will chiefly actuate the lamp. In the latter case the series coil will control the lever, while the shunt will merely retain a hold upon its core so long as the *potential* remains constant. The shunt coil-core in the lamp under consideration is fitted with a means of making magnetic contact with an iron washer in the extremity of the rocking-lever.

Clutch Lamps in General.

The principle of working the lamp with a friction-clutch and wheel is becoming very common. Clutches or drivers of various kinds are used. A very good form is that of a loose steel band encircling the flange of the wheel. A pull from the solenoid or magnet tightens this around the flange, while any further motion carries wheel and clutch forward as one. The wheel almost invariably gears into a rack by means of peripheral teeth or a pinion. Such spring-clutches are either external, as in Statter's lamp of 1885, or internal, as in Siemens' holophote lamp of 1887.

Another order of clutches are those the first of which appeared in the year 1852 in Slater and Watson's patents, and used later by Brush and many other inventors. Toggle-joints have also been resorted to, as in Joel's lamp.

Focussing Lamps.

These are lamps in which, as for lighthouse purposes, the arc must occupy one position. In this case both carbons must be fed as required, and there are several lamps meeting this requirement.

Gaiffe's Lamp.

This lamp bears a strong resemblance in principle to the regulator devised by Archereau, described above.

It has a vertical coil of thick wire (Fig. 102), into which the lower carbon bar, A, is drawn when the current passes. This bar, unlike that used in Archereau's lamp, is toothed throughout a portion of its length, and actuates a wheel of 25 teeth, the axis of which carries another wheel of 50 teeth, insulated from the axis. The second, or largest, wheel engages another racked bar, B, actuating the upper carbon, and any motion of the first bar in its coil gives a rate of approximation of 2 : 1 to the bars, the upper having, of course, to move the faster to make up for the greater length burnt.

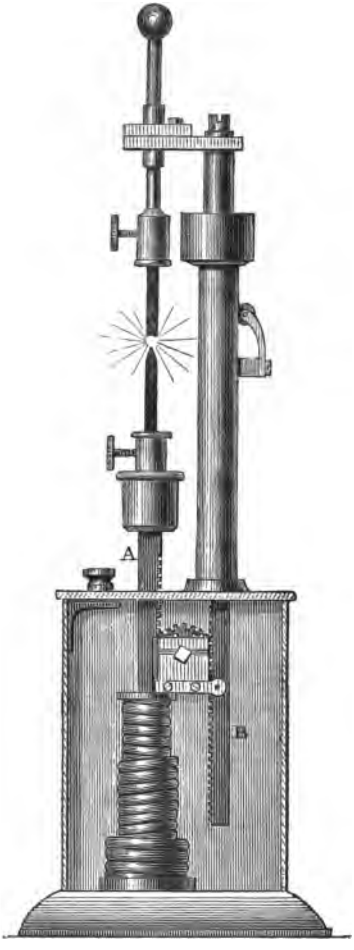


Fig. 102.—Gaiffe's Lamp.

Fig. 103 shows the racks, E and E; F is a pair of wheels bearing the ratio 2 : 1 to each other's effect upon the racks.

In order to maintain the contact between the carbons when the current is not passing, a clock-spring is provided upon the axis of the wheels, and this constantly urges the carbons together. The strength of this spring is such, that the pull of the bobbin upon the lower bar, when the current passes, will overcome it, and separate the carbons to the required distance for the production of a brilliant light.

All the parts of each carbon holder are, of course, insulated from each other. There is a great advantage in this arrangement, as applied to such purposes as require the light to occupy one point continually, such as in lighthouse illumination and the working of various instruments, including optical-lanterns, &c. It is a well-constructed and arranged lamp, and on account of its simplicity its working may be understood at a glance. The Gaiffe lamp is not, however, adapted for the consumption of very large and long carbons. Otherwise it may be said to possess all the advantages claimed for the Serrin lamp. It is fixed upon a steady base, and a circular metallic case encloses the working parts.

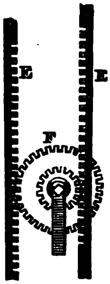


Fig. 103. Lamp Rack-work.

Duboscq's Lamp.

The regulator connected with the name of Duboscq was invented originally by Foucault, though the mechanism has been considerably improved by Duboscq. This lamp is well known in England, as it was for a long time the only efficient regulator of vertical carbons obtainable. It has had considerable application in the production of electric light for demonstrating purposes, such as the experiments of lecturers and occasional displays.

It has the same kind of regulating arrangement as Gaiffe's lamp. The racks are, however, in this arrangement actuated entirely by a clockwork spring and train, and the current only performs the part of stopping and releasing this train when the carbons are apt to go too near to each other, or the current becomes too weak by too great separation of the points.

Fig. 104 exhibits the arrangement adopted for stopping and releasing the train as required. A is a metallic finger or detent, which stops or releases the mechanism contained in a case above. B is a soft iron armature to which the detent is attached; C is an electro-magnet, by which the current is enabled to control the movement of the parts as required. D is an arrangement controlling the spiral spring shown, which balances the attractive force of the magnet when in work.

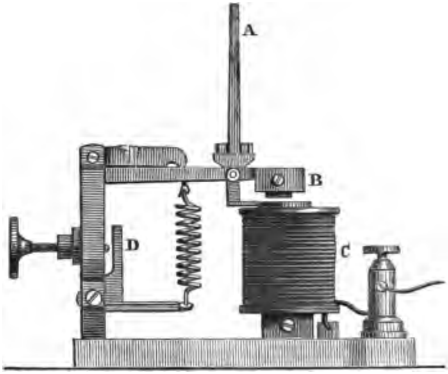


Fig. 104.—Detent of Duboscq's Lamp.

The current may be said to have almost perfect control over the movements of the points, and permits approximation to each other until the arc or separation for light is of a suitable length for the current to maintain. The arrangement D, acting upon the antagonistic spring, enables the adjustment of the lamp to any given strength of current to be easily made by hand before closing the circuit. In this lamp also the points are kept as nearly as possible in one position, and for this reason the arrangement is suitable for lighthouse work.

Siemens' Lamp.

This lamp was originally devised by Herr Häfner von Alteneck, who was the inventor of the particular mode of winding the wire on the armature in the Siemens' dynamo-electric machine in its present form.

As in several other lamps, Siemens' apparatus has the carbon holders racked. The pinions of the racks are on one axis, and of such diameters that the upper carbon has double the run of the lower.

Fig. 105 exhibits the chief peculiarity of this lamp. It will be observed that it consists of an electro-magnet arrangement, A, L, T, through which motion may be communicated to the ratchet wheel, U, by the pawl S. L is the fulcrum of the magnet armature, which is caused to oscillate opposite to the poles of the electro-magnet, E, by reason of a contact-breaking arrangement being

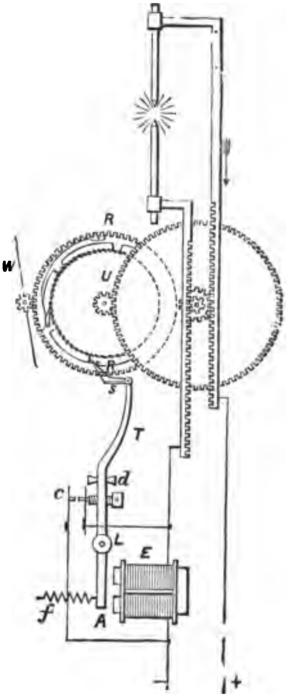


Fig. 105.—Siemens' Lamp.

situated at C, with an adjustable platinum-tipped screw. The armature is pulled from the magnet poles by an antagonistic spring *f*. When the spring is enabled, by the cessation of magnetism in the magnet, to pull to itself the armature, the pawl, S, is compelled by a pin to leave the teeth of the ratchet wheel, U, and the upper rack may then descend, causing, as it does so, the under rack to ascend at half the speed. The current passes, as indicated by the arrow, up one wire and rack and down the other.

This lamp is suited to work either with alternating or direct currents, but if alternating currents are used, there is no need for the contact-breaking stop, C, the change of polarity in the connections giving the required motion.

In the case of a direct current, the action is as follows:—As soon as the current passes, a small light is shown at the point of contact of the carbons, and this passage of current causes the electro-magnet to work the armature with an oscillating motion until the pawl has separated the carbons through the rotation of wheel U. When the separation is sufficient the current is weakened, and the antagonistic spring prevents the weakened magnet from giving further motion to the wheel. A continuous check is thus kept upon the falling tendency of the rack with the upper carbon. This lamp is admirably suited for lighthouse and general purposes.

The Siemens and Häfner-Alteneck Pendulum and Differential Lamps.

The pendulum lamp, the invention of Herr Häfner von Alteneck, recommends itself at once by the almost total absence of wheels and the simplicity of its moving parts. The lower carbon holder is in this lamp a fixture, and the upper carbon holder is formed by a rack, which in sinking down turns a pinion. In order to moderate the speed with which this pinion turns, a common escapement-wheel with its pendulum is fixed to the same axle. A movable frame, serving as a guide to the upper carbon holder, carries the pinion, and the pendulum, being lifted, more or less, by a solenoid acting on an iron core connected to the framing. During the normal burning of the lamp, a small lever fixed to the movable frame catches the pendulum, preventing it from moving, and thus keeping the upper carbon holder stationary. When the arc becomes too large, or the current is weakened by other causes, the solenoid will let the frame drop a certain distance; the free end of the little lever is arrested by a projection of the lamp-casing, and the pendulum is free to move. The upper carbon will then at once descend, but as soon as the distance between the carbons is diminished, the strength of current will increase, lift the frame, and the little lever will again stop the downward motion of the upper carbon holder. In order to lessen the suddenness of the motion of the framing, an air-pump is connected with it, and a spiral spring is attached to the core, by which the attractive force of the solenoid can be more or less assisted according to the strength of the current. In practical work this form of lamp has proved to be very efficient, as its management is easily understood. Similar lamps have been used in the British Museum, where all the apparatus has been managed, after the first fortnight, by the Museum authorities themselves, and no difficulty has been experienced by them in maintaining the regulators in good working order. Lately these lamps were exchanged for others which work on the same principle, but have the case containing the solenoid and the moving frame above the point of light. This modification has been adopted because it facilitates the construction of suitable lanterns, but it does not differ from the form first described in the way of regulating the approach of the carbons.

In the lamps just described, as in most of those of other makers, the strength of current regulates the distance of the carbons, and the consequence is, that it is not in every case practicable to connect two or more of them in one circuit. To overcome this difficulty, Mr. Von. Alteneck used another principle, which in some respects resembles that of the pendulum lamp. The upper carbon is attached to a similar rack moving in a slide, and turning a pinion with pendulum attached, but the motion of the movable frame is governed by *two* solenoids instead of one. The frame is attached to a lever, which carries a double iron core reaching into the two solenoids. One of these acts in the same way as the solenoid of the pendulum lamp, separating the carbons whenever a current passes through it. The other one consists of fine wire having a high resistance, and forms a shunt to the main circuit, the ends of the fine wire being connected direct to the terminals of the lamp, and by attracting its core it brings the carbons together or releases the pendulum respectively. The action of these solenoids will, therefore, be balanced when the difference of potential on the two sides of the arc is of a certain magnitude, depending on the relative position of the two coils and the resistance of the wire on them. By this arrangement the quantity of the current flowing through the lamp has no influence on the relative position of the carbons, and nothing prevents a large number of them being inserted into one circuit. In producing light by alternate currents as many as 24 of these lamps have been worked in series, and their behaviour was all that could be desired. In order to make these lamps independent of each other a little contact piece is attached to the movable frame, which makes a short circuit from one terminal to the other whenever the frame is in its lowest position.

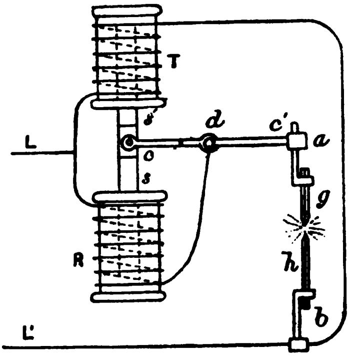


Fig. 106.—Siemens' Differential Lamp.

The principle of the action in this differential lamp is exhibited by Fig. 106, where *g* and *h* indicate the carbons held respectively in the sockets *a* and *b*, and provided with means of feeding as they are consumed. One socket, *a*, is attached to one arm, *c'*, of a lever pivoted at *d*, and having its opposite arm, *c*, connected to a piece of non-magnetic material uniting a pair of iron cores, *s s'*. The core *s* is free to play up and down within a solenoid R, the coil of which is of large wire offering small resistance, and forms part of the lamp circuit. The core *s'* is free to play up and down within a solenoid T, having a coil of smaller wire offering a greater resistance than the coil of R. The coil of T is in a circuit external to the lamp, that is to say, joining the conductors L L′, excluding the carbons. When the solenoid R, being excited, draws in its core *s* the points of the carbons are separated; when on the other hand the solenoid T draws in its core *s′* the carbons are caused to approach each other. As the relative force of the two solenoids depends upon the strengths of the currents of electricity passing respectively through the coils, and as this depends upon the relative resistance of their respective circuits, the one circuit, consisting of the coil T and its connections to the main circuit of L L′, and the other, consisting of the coil R, the two carbons, and the arc between them, that portion of the latter which consists of the arc being dependent on the distance of the carbons apart, this distance will become adjusted automatically by the action of the two solenoids, so as practically to maintain constant the action of the lamp. If, for example, the carbons should be too near together, a larger proportion of the electric current passing through coil R than through coil T will cause the superior attraction of the core *s*, separating the carbons, and thereby increasing the resistance of the arc between them, and so lessening the quantity of electric current that passes through them. If, on the other hand, the carbons should be too far apart, then the coil R, being less excited than the coil T, will exert less attractive force on its core *s*, permitting the other core *s′* to be drawn into its coil, and thus causing an approach of the carbons which will lessen the resistance of the arc between them, and so permit the passage of a larger proportion of the current through them; thus the regulation of the lamp being dependent only on the resistance of its voltaic arc, and independent of the strength of current, the action of any one lamp in a circuit will not affect that of other lamps in the same circuit, and consequently a number of such lamps can, by means of this invention, be effectually worked in one and the same circuit.

Both in the "pendulum" and in the "differential" lamp the lower carbon is fixed, the focus of the light will therefore gradually descend. For some purposes it is, however, necessary to keep the focus in the same place, and Dr. William Siemens suggested a simple contrivance to attain this end. The lower carbon is enclosed in a tube and, by means of a fine wire, a roller and a weight, is pushed against a screw fixed to the upper end of the tube. As the carbon wastes away by the action of the current, fresh carbon is fed upwards by the weight, and the shape which the carbon assumes admits of the screw being far enough away from the arc to prevent its being injuriously affected by the heat. It is obvious that in such a case much longer carbons can be used, and that the time during which a lamp can remain alight without removal of carbons, is thereby very materially increased.

This "abutment" pole is employed for both electrodes in the last form of lamp invented by Dr. William Siemens, but the screw, against which the carbons are pressed, has been replaced by a knife-edge, which appears to give better results. In this lamp the carbons are placed horizontally, and their tubes are attached to bell-crank levers, the other ends of which support the core of a solenoid, on which fine wire is wound, forming a high resistance shunt from one terminal to the other. The action of the lamp is very simple; the weight of the core, which can be varied at will, keeps the carbons apart when no current passes. As soon as a current arrives the solenoid will lift the core, the carbons touch for a moment and the arc is established, the further regulation depending again on the difference of potential *only*, and being independent of the *strength* of the current. No wheels whatever enter into the construction of this lamp, and all its parts are exceedingly simple.

Thompson-Houston Lamp.

This has been one of the most successful lamps. It depends upon the clutch principle, somewhat as used by Brush and others. The diagram (Fig. 107) represents the main portions of the lamp and the connections to the coils. The shunt and series coils control the magnetic pull of two conical pole pieces, the extremities of which move the upper and lower ends of a rocking-lever, *a*, pivoted there. This lever has an extension, *b*, the amplified movements of which are controlled by an air dash-pot. This extension carries a clutch-piece, *c*, jointed to an upper clutch-piece, *d*, and the upper carbon-rod of the lamp passes through narrow apertures in both. Now, if the series (lower) coil were to pull inwards the lower extremity of the lever, *a*, the twin clutch would close together, so nipping the carbon, raising it, and establishing the arc. As the arc increases in length, so weakening the *proportion* of current passing in the series coil, the portion passing in the shunt coil increases, and that coil begins to exert an effect upon its (upper) end of the lever. The carbon is thus released by the clutch being partially opened, and the arc shortened by the carbon falling the required distance. Too sudden a fall would be at once checked by the current in the series coil becoming proportionally stronger. Thus, as in most lamps of this type, the arc is "struck" by the main current and "fed" by the by-pass or shunt.

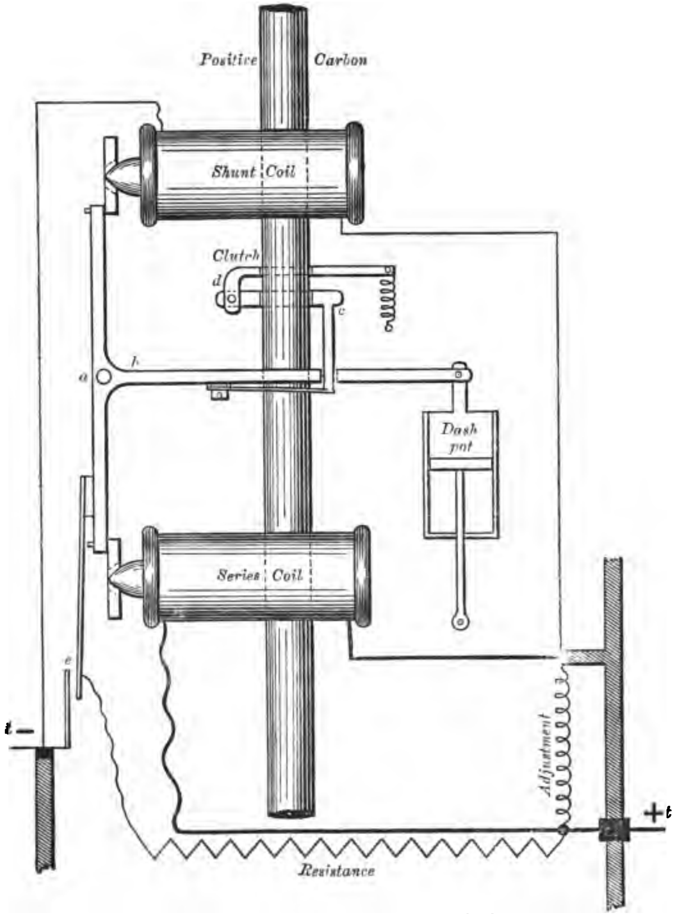


Fig. 107.—Thompson-Houston Lamp-Action.

Should the lamp from any cause become extinguished, and the current interrupted through the lamp proper, an augmentation of the current in the shunt, with the corresponding weakening of the series coil, would cause the lever, *a*, to move to the left at the bottom, so making a main circuit contact at *e*, through the resistance, so crossing the lamp out of circuit. The current then would flow direct from $t+$ to $t-$. The resistance coil is intended to be equal to the average resistance of the lamp. The adjustment coil is used to suitably balance the lamp at the outset.

Lontin's Lamp.

M. Lontin, inventor of the Lontin dynamo-electric machine, has sought to improve upon the well-known Serrin lamp by introducing parts for its working of greater simplicity than hitherto.

It would appear that this inventor bases one part of his improvement upon the Serrin lamp upon the expansion of a metallic bar by the passage of the current through it, and by substituting this bar for the electro-magnet employed in Serrin's lamp.

M. Lontin has also invented a form of lamp in which any length of carbon-rods may be employed. The lamp and carbons in this invention are horizontally placed, instead of vertically, as in most other lamps. The carbon holders are hollow throughout, so that any required length of rod may be inserted in them.

One of the carbons, as it passes through its support, is moved by a pair of rollers bearing with gentle pressure against it. This rotation is kept up by bevel wheels actuated by a spring and clock movement in the case of the lamp.

There is a disadvantage, however, in placing the carbons horizontally. Vertical arcs are found to be much more effective, current for current, than horizontal arcs.

Carre's Lamp.

The inventor of the Carré induction (high tension) machine has produced a lamp which is judged by some to be an improvement on Serrin's lamp. He employs a double solenoid instead of an electro-magnet, which is supplied with an armature of S shape. This armature is caused to oscillate round a spindle, or pivot axis, at its centre, and the two ends enter a curved bobbin. When, from any cause, the current is interrupted, this armature is withdrawn by springs as usual, a detent releases the mechanism, and the carbon points come into close contact, so re-establishing the current. As in Serrin's lamp, the mechanism of Carré's device is actuated by the falling weight of the upper carbon holder.

When the current passes, the ends of the armature are sucked into the solenoid, and the carbon points are at once separated to the distance required to produce the voltaic arc.

Brush's Lamp.

The arrangement of the controlling device in this lamp admits of a large number of arcs being maintained in one circuit. The lamp consists essentially of three parts, namely, an arc-regulating device in two parts, and an automatic "cut-out," which throws the lamp out of the circuit if it becomes faulty.

The arc-controlling arrangement consists essentially, in the first place, of an electro-magnetic solenoid A (Fig. 108), forming a hollow cylinder. It is wound, in reverse directions, with two helices of wire, consisting, the first, of one or two layers of thick wire, and, secondly, of several layers of fine wire. The thick wire coil is in circuit with the arc, and offers no appreciable resistance, and the most of the current passes through it. The thin wire coil is really a shunt to both the thick wire coil *and the arc*, and offers a resistance of about 200 ohms; thus, as long as the current passes through the carbons a small portion of the current passes through it and around the cylinder in the *opposite* direction to the course of the main current. The electro-magnetic effect of the thick wire solenoid is therefore partly neutralised by that of the thin wire solenoid; for although only a hundredth of the main current flows through the fine wire coil its influence upon the attractive power of the cylinder is very con-

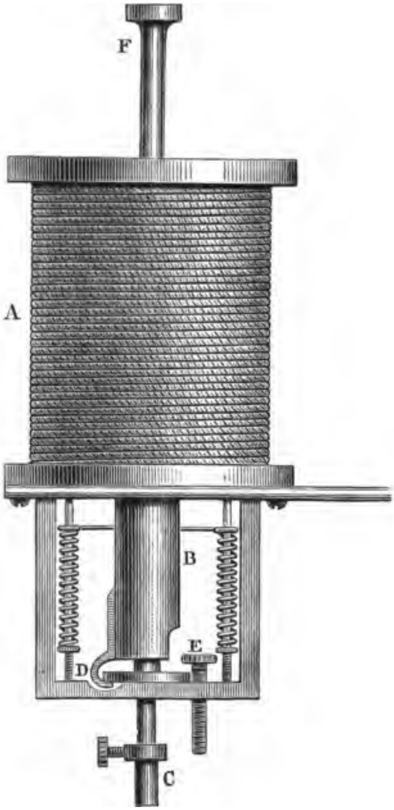


Fig. 108.—Part of Brush's Lamp.

siderable, owing to the greater number of convolutions it takes around the core. The real part played by this device is described further on. Meantime, it is necessary to describe the nature of the device by means of which the motion of the carbon is controlled. In this lamp the lower carbon is fixed; the upper carbon-rod is therefore that under the control of the current.

B is a hollow iron core, fitting easily into the aperture in A. This core is free to move up and down a short distance. Within the core, B, is a brass rod, C, which also constitutes the upper carbon holder. This rod is loose in the aperture of D. At D is shown a lifting finger attached to B; its extremity is curved and passes underneath a brass washer or annular clutch, D, placed somewhat loosely on the rod C. This annular clutch is otherwise quite free.

E is a set screw, which is adjusted by hand. It is intended to control the movements of the clutch, D, by being screwed more or less down upon it.

If one wire from the dynamo-electric machine is connected to the lower carbon, while the other is connected to the commencing end of the wire coil, A, the other extremity of which communicates with the upper carbon holder, the current will pass through the thick wire coil, the upper carbon, the arc, and the lower carbon, so completing the circuit. The core cylinder, B, is then, by the force of the magnetism created, drawn up into the interior of A. By means of the lifting finger, D, it raises that edge of the clutch, until, by the latter's angular pressure upon it, the rod C is lifted upwards, and will be raised to such a height as may be determined by the height of the thumb-screw, E. As long, then, as the magnetism remains the same, the rod C, with its upper carbon, will remain fixed. While the current is not passing, the rod, C, is quite free to descend until its carbon point is supported by the lower carbon. This is the condition of the parts when the lamp is out of action, or when, by accident, the circuit is broken.

As soon, however, as the current passes, the core, B, is sucked into the cylindrical cavity of the bobbin, A, and in being raised also raises the washer by its finger, D, and with it the rod and upper carbon, C, until the voltaic arc is established between the carbons.

A pair of springs is represented in the figure, one on either side of the core, B. The function of those spirals is to support the weight of the core, B, with the aid of the induced magnetic attraction when the current passes. As the carbons are consumed the length of the voltaic arc increases, and with the increased resistance the current diminishes in strength. This weakens the magnetic pull of the wire coil, and the core, B, with the rod, C, and upper carbon move downwards by the action of gravity, until the consequent shortening of the voltaic arc so diminishes the resistance and increases the strength of the current that this downward movement is stopped by the increasing pull of the magnetic helix, A; or the clutch washer, D, will reach its floor or plate and its downward movement will be stopped, when any downward movement of the core, B, however slight, will at once release the rod, C, by allowing it to slide through the washer until the washer is again tilted by the upward movement of the core, B, due to an increase of magnetism.

The carbon holder rod, C, is hollow, and contains a mixture of glycerine and water, in which a small piston or valve is hung from a cast-iron hood, in order to prevent the upper carbon from falling too rapidly when released. This arrangement is called a "dash-pot."

So far, the action of the solenoid is much the same as that in other lamps; but the distinguishing characteristic of Brush's lamp lies in the counter-controlling influence of the fine wire shunt, before mentioned. It will be clear that when the current flows it passes in opposite directions around the soft iron core, and that the latter will be attracted upwards if the current in the thick wire coil preponderates over that in the thin wire coil. If under these conditions the arc should become too long, the current through the thick wire will be weakened, and that in the thin wire will be proportionately strengthened. The pull upon the core will therefore be weakened, and the upper carbon will slide slowly downwards until the arc is shortened and the current through the thick wire strengthened. If the arc should become too short, the current in the thick wire will be increased and that in the thin wire diminished. The iron core will therefore be attracted upwards, and its annular clutch will raise the upper carbon until the length of the arc balances the attractive power of the solenoid.

It is this arrangement which allows of several of the arc lamps being included in one circuit. As many as forty, or more, arcs are so included in the working of the Brush system.

In the ordinary arc lamp we may conceive the secondary or shunt solenoid absent, and it will not be difficult to see that the regulating of its arc will depend entirely upon the strength of the main current. Hence, when more than one common lamp is so worked in one circuit, confusion at once ensues. In the Brush system, as in that of Siemens' *differential lamp*, the arc is controlled not by the strength of the main current, but by the *difference* between the influence of the thick wire solenoid and that of the thin wire solenoid. The Brush lamp is therefore also a differential lamp.

But although the differential regulator serves to control the arc of the lamp while the circuit is complete, and although it effects this quite independently of the main current strength, a serious defect would still exist in the system if the lamps were liable to become extinguished, because the interruption of the current in any one lamp would extinguish every other lamp in that circuit. The second distinguishing feature of the Brush lamp overcomes this difficulty in a most ingenious manner. An automatic "cut-out" is arranged, and so adjusted that if the carbons should burn out, or by any other accident the current should be interrupted, the whole lamp may be thrown out of the circuit.

This is accomplished by means of another but smaller solenoid, similar to that already described. This solenoid is also wound with a short thick wire and a long thin wire. The long thin wire is in circuit with the thin wire of the arc-regulating solenoid. The thick wire, when in circuit, forms a shunt or by-pass to the whole lamp. Should the lamp become extinguished from any cause, as from the burning out of the carbons, the current in the fine wire of the arc-regulating solenoid would become abnormally strong. The same current would flow through the "cut-out" solenoid, and cause it to close the main circuit through its short thick wire, so throwing the arc-regulating solenoid out of the circuit. The current would then flow past the faulty lamp to the next.. In the "cut-out" solenoid both currents flow in the same direction.

These arrangements are represented in the diagram Fig. 109. A represents the arc-regulating solenoid,

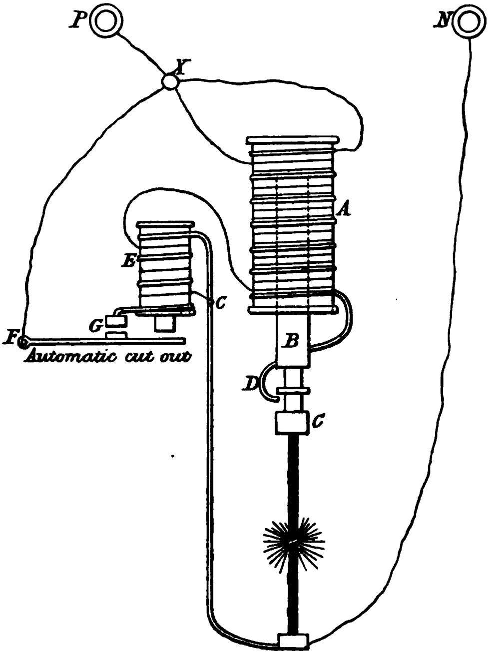


Fig. 109.—Diagram of Brush's Lamp.

the main current from the junction-point X being divided into two branches, part of it flowing through the fine wire, which encircles both solenoids, and so to C and N, and the rest through the thick wire of A, and so through the arc to N. E represents the solenoid or electro-magnet of the "cut-out." The thick wire with which it is encircled terminates at the block G and is in connection with N. F represents an iron armature, which is normally kept away from E by an antagonistic spring. When the current at the arc altogether fails, that portion flowing through the fine wire of E will become abnormally powerful, and E will attract F, and so close the thick wire shunt at the point G. This short-circuits the arc and the solenoid A, the result being that the proportion of the current now flowing in the fine wire is very small, and E would loose its power to attract F, did not the main current now flow in the thick wire round E. F, therefore, will maintain the contact at G so long as the current continues to flow in the circuit.

The ordinary length of the carbons employed in the Brush lamps is 12 inches. They are usually copper-coated to increase their conductivity, and vary in diameter from $\frac{7}{10}$th inch to 1 inch, according to the power of the arc to be produced.

The ordinary lamp with a single pair of carbons burns eight hours. The Brush lamp with two pairs of carbons burns sixteen hours. In this lamp one arc-regulating solenoid controls both carbon-rods. The annular clutches upon the rods are so adjusted that one raises its rod $\frac{1}{4}$ inch above the other, so that the second pair of carbons do not come into action until the first pair are burnt out and allow the second carbons to fall into contact.

Wallace-Farmer Lamp.

Fig. 110 is an illustration of this lamp. A A are two *plates* of carefully prepared carbon, and the object of the invention is to so cause the light to burn between them, that the automatic adjustment so often necessary in other lamps is here only necessary about every half-hour. The plates in the latest form of this lamp are about 9 in. long, 5 wide, and the upper is double the thickness of the under—this thickness in turn depending upon the strength of the current to be employed. The lower plate is fixed to the frame, but the upper plate is under the control of an electro-magnet through the rod B. This provides for the contact between or separation of the plates, as the current may require, to produce the maximum amount of light. The electro-magnetic arrangement, C, consists of an ordinary electro-magnet, having its poles downwards, and the rod D B has attached to it a soft iron armature. When no current passes, the electro-magnet has no effect, and one carbon rests upon another; but when the current is passed, the

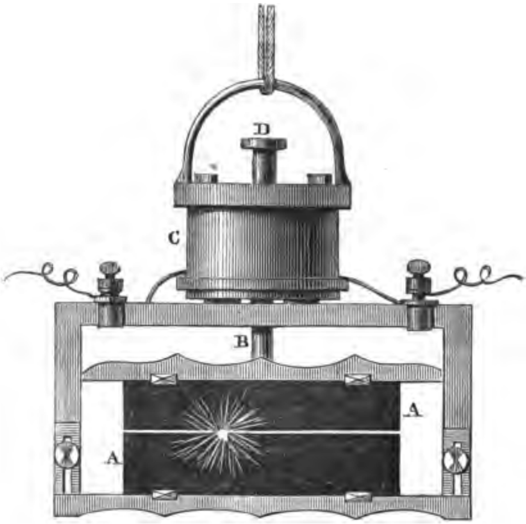


Fig. 110.—The Wallace-Farmer Lamp.

arc of light forms where there is least resistance, and the electro-magnet at the same instant pulls up the upper carbon and makes the required separation. The distance between the plates may be regulated to a nicety to suit any current.

The light, as before stated, starts at the point of least resistance, and it burns its way horizontally along the carbon edges and back again until the arc is too long, when it is necessary to screw down the rod D a turn or two. In this way the lamp may burn for many hours at a time. As many as 10 of these lamps have been maintained in circuit of a Wallace-Farmer machine. It was tried in England, and gave considerable satisfaction. It is, however, unsuited to purposes requiring the light to be kept in one point.

Rapieff's Lamp.

The leading peculiarity of M. Rapieff's lamp consists in the use of duplex carbons. Most other lamps employ only one solid carbon-rod for each burning point; but Rapieff uses two—that is, four altogether. These rods are inclined to each other to form one upright and one inverted V, and at the point of intersection the electric arc is produced as in other lamps. The rods used by this inventor are necessarily of half the sectional area they would have if not double.

Fig. 111 will give some definite idea of these arrangements, where the four rods are represented in the interior of a glass globe nearly in contact. The upper pair of rods are always the longer, because they burn away the faster. The duplicate arrangement of the rods presents the advantage that one of them may be removed and renewed without extinguishing the light. This is the chief feature of the whole arrangement.

M. Rapieff also recognises the advantage of making the electrical contact with the rods as near to their points as possible. This has the effect of greatly decreasing the resistance of the lamp.

The upper carbons are free to slide in their holders, and as their points come into actual contact, they are stopped from further motion. As far as this end of the circuit is concerned it is self-feeding, for as fast as the points burn away the length is renewed by their weight pressing them downwards.

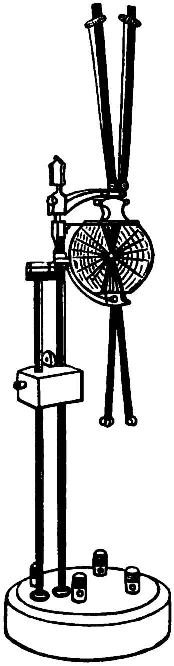


Fig. 111.—Rapieff's Lamp.

When the current is interrupted, the two pairs of points come together by movement on the part of the lower pair only. As long as the current does not pass, a light spring supports the lower pair, and gently presses them against the upper pair. Fastened to the free end of both upper carbons is a silk thread, which passes over a pulley, and is attached to a sliding-weight in the supporting pillar of the lamp. When the current passes, the lower pair of carbons is caused through its spring to be separated the required distance to produce the arc. There is communication between the vertical rod actuating the lower carbons and an electro-magnetic arrangement concealed in the base of the lamp.

This consists simply of two electro-magnets, one of which is fixed to the base, while the other is pivoted or hinged, and by its approach to the fixed one moves the vertical rod controlling the lower carbons, and these are thus drawn away from the upper pair. When the current ceases to flow, the spring before spoken of causes the hinged magnet to fall into its normal position, and the lower carbons at the same time touch the upper pair, to be in readiness to start the light when the current next passes.

Another good feature of the Rapieff lamp is its arrangement (also concealed in the foot) for throwing a resistance of wire, equivalent to that of the lamp, into circuit when, through any cause, the circuit has been interrupted in the lamp. When the hinged magnet falls back, it instantly closes the circuit of this resistance of wire, and the machine is not affected, nor does it (the supposed accident) affect any other lamps in the same circuit, since the resistance remains constant, or very nearly so. There is also employed in these lamps, instead of a coil of wire, a resistance consisting of a pencil of carbon, and through this, the resistance of which is equal to that of the lamp, the current passes when the lamp breaks circuit.

By means of these carefully thought out arrangements, as many as 6 and 8 lamps of this type have been kept alight upon one circuit only, and any accident to one lamp did not affect the others; or any lamp might be extinguished and re-lighted without any effect being apparent upon the main circuit.

This system has been in practical use in the composing room of the *Times* newspaper. The construction of the lamp is not so well carried out as the plan, and the parts are unnecessarily delicate, which should not be the case in a practicable lamp for general use. M. Rapieff has also brought into use a lamp in which both pairs of carbons pass up from underneath, forming an inverted V. The arc impinges upon a piece of lime, which increases the light. M. Rapieff has also invented an electric "candle."

Crompton's Lamp.

In this lamp the inventor has aimed at reducing the weight of those parts that require movement for the more delicate and final adjustment of the distance between the carbons. In its latest form the mechanism is above the light. The negative carbon is below the positive, and attached by an arm to a rod fast to the armature of the magnet. A spring keeps the armature and rod up, when the magnet is not acting. The positive carbon is fast to a rod which by its weight constantly tends to descend towards the negative carbon, and in doing so, by means of a rack, causes a train of wheels to work.

On the top of the armature of the magnet is hinged a smaller piece of iron, or jockey armature, carrying a brake which can act on the train of wheels. A small light spring keeps the brake from touching the wheels until a current sufficiently strong causes not only the armature to be drawn down and come in contact with the magnet, but also causes the smaller jockey piece on the top of it to be drawn down and apply the brake. The action is as follows: 1. When no current is circulating, the positive descends and touches the negative. 2. On a current being established, the electro-magnet draws down the armature, thus lowering the negative away from the positive and establishing the arc. 3. The positive then begins to fall until the current becomes sufficiently strong to attract the small jockey armature, causing the brake to be applied and stopping the descent of the positive. The lamp is very sensitive, as, instead of having several pounds to be thrown in and out of motion for each adjustment, the portion to be moved by the change of current is only a few grains. The adjustment consequently takes place every few seconds.

Weston's Lamp.

The action of this lamp is similar to that of the Brush. Instead of a solenoid Mr. Weston employs a pair-limbed electro-magnet, which is coiled with two wires. One of the helices is of thick wire, and carries the greater part of the current; the other is of finer wire in a larger number of convolutions, and conveys a percentage of the current; it thus forms a shunt to the arc.

The Pilsen Lamp.

The special feature of this lamp lies in the use of a bi-conical or spindle-shaped iron core. When such a core is suspended between and partially through the interiors of two electro-magnetic solenoids, placed one above the other, and an electric current is passed through the solenoids, such a core has no positive or balanced point (as is the case when a plain cylindrical core is used), and it thus has a lengthened extent of movement vertically in the solenoids. This principle is utilised directly in the regulation of the arc and in feeding the upper carbon downwards. The lamp is also made with two conical cores moving in two separate solenoids placed side by side.

The lamp consists essentially of a soft iron core of the shape described, *a* (Fig. 112) and of two solenoids, *b* and C. *b* is wound with fine wire, and forms a shunt or by-pass to the arc from the point *d* to the point d^1. C is wound with thick wire, and is in direct circuit with the arc.

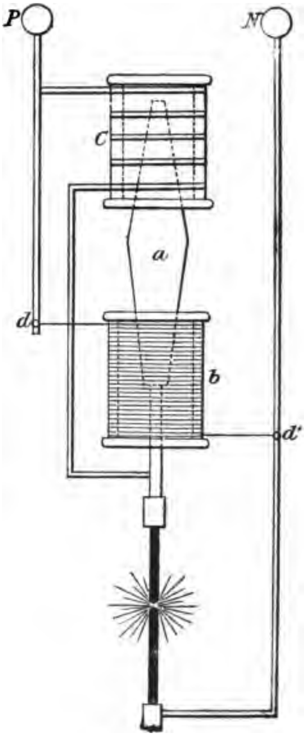


Fig. 112.—Diagram of the "Single Core" Pilsen Lamp.

The resistances and electro-magnetic influence of these two coils are so balanced that, although about 1 per cent. only of the current flows around *b*, they have equal effect upon the core when the length of the arc is properly regulated (from 1 to 2 millimètres).

Any alteration in the resistance of the arc, by its becoming too long or short, disturbs this balance, and one or the other of the solenoids begins to act, by attracting the core downwards or upwards. If the arc becomes too long, by the burning away of the upper carbon, the current in C will become weak, and that in *b* proportionally stronger. Hence, the electro-magnetic attraction of *b* will preponderate on that of C, and the upper carbon will descend until, the resistance of the arc being reduced, the current in C will balance the effect of that in *b*. Should the arc become too short, the proportion of the current flowing through *b* will be diminished and that through

C augmented; therefore *b* will release and C will attract the soft iron core, raising the upper carbon to the required distance. The influence of the solenoids upon the core is assumed to be the same for all positions of the core within them.

Rotating Disc Lamps.

Many attempts have been made since 1846 to produce a good lamp having rotating discs of carbon instead of the usual rods. Wright was the first to employ this idea, and it has been taken up by several others, with modifications and improvements from time to time.

The discs revolve regularly upon two metal axles, put in connection with the poles of the battery or other generator of electricity, and present successively, by the combined rotation and approximation provided, all the extreme points of their circumferences to the production and emission of the electric light. At each revolution of the discs they are caused to approach each other by the distance they have burned inwards from the edge, to make the length of the arc constant.

Many different kinds of apparatus may be employed to cause the discs both to regularly rotate and also at each revolution to approach each other by the exact distance consumed. It has been done by means of clockwork and a spring or weight, and electro-magnetism is, of course, also available for the same purpose. Le Molt, whose lamp was produced and patented in 1849, produced the motion by the first method, and he employed cams upon a large brass disc to make up for the burnt portion of the carbon discs employed. This lamp would burn for over 20 hours at a time.

A great objection to this class of lamps lies in the fact that it is almost impossible to produce discs of sufficient purity to burn equal spaces in equal times, so that a regular motion is in practice of no use. The motion, however it is produced, must be under the direct control of the current itself, so that any augmentation of space burnt over may be compensated for by greater speed in the discs, and a decrease of carbon space burnt by less speed. Arranged vertically, one disc edge above the other, and thus controlled, there is no reason why this should not make a good continuous lamp.

Lamps in which the Carbons touch.

In the lamps previously mentioned, the carbons are, by clockwork, electro-magnets, or weights, kept automatically at a distance apart, so as to form the voltaic arc; in another class of lamps the carbons actually touch, and the light is emitted through the incandescence of the carbon at and near the points of contact, and also by arcs formed between points immediately around the points of contact, the resistance at the point of contact being sufficient to cause a portion of the current to form a belt of heated air forming the arc between the portions of the carbon situated near the point of contact.

Reynier's Lamp.

Reynier's improved lamp works with a rod and a disc of carbon. The rod is placed vertically, as usual in other lamps, and fixed to the upper arm. This upper arm of the lamp is movable, as in Serrin's lamp, and is also toothed. The support and the carbon-rod thus move downwards together.

The racked bar, as it descends by its own weight, carrying its carbon-rod, is made to impart motion to a pinion, which in turn rotates, through a larger wheel, the carbon disc employed. Thus the disc rotates in obedience to the descent of the upper carbon, and it will be evident that the carbon-rod also acts as a brake upon the rotating disc to prevent too free a motion.

One peculiarity of the Reynier lamp is its employment of incandescence in the rod used. This carbon pencil is small although long, and the current is not made to traverse the whole of its length. The current is communicated to it a little way above its contact with the revolving carbon disc, and the part of the rod between where the contact is made with the conductor and its end is made white-hot, and emits considerable light and heat.

It will be inferred that the unequal burning away of the disc, as it is softer or harder, must cause irregularities in the light, and this is in the foregoing construction really the case.

Some recent improvements effected by the inventor, however, make the light almost perfectly steady. The revolution of the turning disc is obtained from the tangential component of the pressure of the carbon pencil on the circumference of the disc. Thus the burning end of the pencil never leaves the moving contact, and it is said that all previous causes of irregularity are thus obviated. There is a brake retarding the progress of the rod, and it is operated thus:—The contact wheel is carried by a lever. The pressure exerted by the carbon on the wheel causes a shoe to press upon the face of a wheel, which is revolved by means of the weight of the holder rod through its rack and pinion. This lamp is suited for the weakest currents and displays of light, down to the current from a few of Bunsen's cells.

Werdermann's Lamp.

The principle embodied in the construction of this lamp is of much value. It is almost a true incandescent lamp, and in this respect may be compared to the Reynier apparatus.

Fig. 113 represents one form of the Werdermann regulator. A is a rounded block of carbon, connected to the negative wire from the electric source. B is a rod of carbon, constantly urged upwards against A by a weight, G, acting through a cord over a pulley as shown. It will thus be observed that the lamp is altogether of very simple construction, and has no clockwork or other regulating mechanism.

The inventor states that there is a repulsion between the carbon block and the point sufficient to cause a slight separation, so that the lamp is not simply an incandescent one, but possesses some of the peculiarities and advantages of open circuit lamps. When the current is passed, the carbon-rod, at its upper extremity, becomes incandescent, and glows with a clear, steady light. For this purpose a thin rod is used.

The chief advantage claimed by the inventor lies in the fact that several of these lamps may be placed in one circuit, or, more correctly, in multiple arc connection with the electric source. This connection is made by taking two straight wires from the machine, but not joining their ends, and then placing the lamps so that they may connect the two wires together through them. The current is thus divided between the lamps, and the result is, or should be, an almost perfect subdivision of the currents. The number placed in one circuit is limited, however, for when too many are included, the subdivision does not hold good unless the main conductors increase in size with the number. As many as from 9 to 12 lights of 50-candle power have been maintained with a current from a Gramme plating-machine. When only 2 lamps were

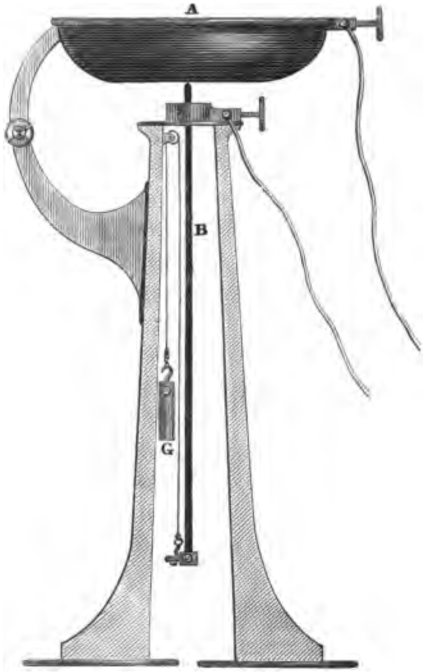


Fig. 113.—Werderman's Lamp.

upon the circuit they gave, each, a light equal to 320 standard candles.

In later forms of this lamp, a disc or cylinder of copper is substituted for the carbon disc. The principle of the lamp is in other respects the same.

The Brougham-André Lamp.

In this lamp a carbon-rod, weighted, falls on to a cone of copper, the carbon being the positive electrode and the copper the negative. The carbon-rod is inside a brass tube, and the copper cone is fast to an arm connected by a rod to another tube outside the one containing the carbon-rod, and insulated from it The outer brass tube is joined to a brass disc, to which is fastened the glass case enveloping the light, and this is kept air-tight by being immersed in a second glass case filled with water. Thus an air-tight joint is obtained and the light soon exhausts the oxygen, leaving gases which do not combine with carbon.

While the carbon burns away at the rate of six inches per hour in the open air, it is said to burn only one-eighth of an inch per hour when in the water-covered globe.

Joel's Lamp.

This is a semi-incandescent lamp, in which a pencil of carbon is caused to impinge upon a disc of copper. The light is partially due to the highly incandescent condition of the extremity of the carbon pencil, and partially to a voltaic arc formed between the copper and the pencil. This arc is supposed to be due to a kind of repulsion between the carbon and the copper disc. The carbon pencil forms the positive pole from the electric source, and is consumed away. The copper being highly conductive, and forming, as it does, the negative pole, is scarcely, if at all, consumed in the arc. The pencil is fed up to the copper disc by means of the gentle pressure exercised by a weight and cord.

The foregoing lamps, in which the carbons touch, are, though simple in construction and action, exceedingly uneconomical.

Electric Candles.

In all the arrangements previously described some means of moving the carbons, either by springs, gravity, or electricity, is employed, but if two rods of carbon are placed parallel, the arc, it is found, can be maintained between them, if the currents are used alternately in different directions, so as to consume the carbons equally. This idea first occurred to M. Jablochkoff, and is called an electric candle, as the carbons consume away from one end in the same way as the wick and wax of a candle. It was first thought necessary to have an insulating material between the rods, but this has been found unnecessary.

M. Jablochkoff's Candle.

By his invention of the "electric candle," M. Jablochkoff, in 1876, instituted a remarkable movement towards the application of electric light to public purposes. In Paris it took the form of lighting the Avenue de l'Opéra, the Place de l'Opéra, the Place du Théâtre Français, and numerous public buildings; and in consequence of the success attending these applications of the new light, it was tried successfully in workshops, railway depots, and other places on the Continent and in America, while the same impetus carried the electric light to the Thames

Embankment and other public places in London and the provinces.

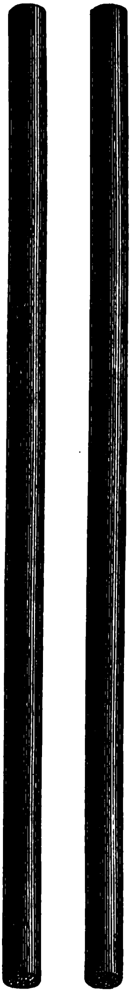


Fig. 114.—Carbon Rods.

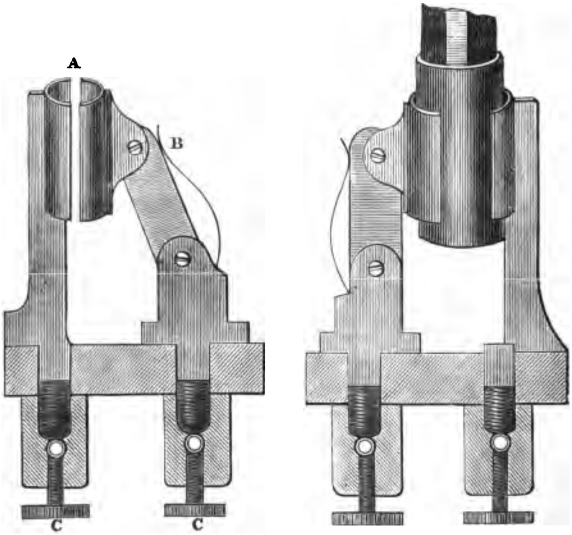
Fig. 115.—Complete Candle.

The "candle" just mentioned consists of two rods of manufactured carbon, placed side by side, and insulated from each other by a strip of plaster of Paris, or kaolin, which was at first used for the purpose. Figs. 114 and 115 represent the rods and the complete candle. The rods used are about $\frac{3}{16}$ths of an inch in diameter, and from 5 to 15 inches in length. They are fastened in a pair of brass tubes, which are held together by an insulating cement, B. Across the top is a chip of carbon fastened in place by carbon powder and gum, and when the alternating currents pass this is fused and the true electric arc instituted.

Fig. 116 is from a photograph of a candle partly burnt, and shows the form assumed by the extremities of the carbon-rods while in use. Both rods burn equally, on account of the alternating currents, which must always be employed with the candle with this object. The plaster of Paris is fused as the candle burns down.

The candles most in use are ten inches long, and burn for about 1½ hours. If this form of candle becomes extinguished, the arc cannot again be conveniently relighted—that is, it will not relight itself. Four candles are placed in one lamp, which has usually a cover of opalescent glass to tone down the intense glare. When one candle burns out, or before it burns out, another is switched into the circuit by an automatic arrangement.

Fig. 116.—From Photo of half-burnt Candle.



Figs. 117 and 118.—Jablochkoff's Candle-holders.

Figs. 117 and 118 represent holders for the candles. They consist simply of two cheeks insulated from each other, one of them A, fixed, and the other articulated with a holding spring, B. The binding-screws, C C, convey the current to the holder.

One form of the automatic switch consists of a metallic finger, which is pressed against the candle by a spring, so that when the candle is consumed down to this point the finger will fall through it, and by a contact lever underneath switch another candle into circuit. Other more or less complicated arrangements are in use for the same purpose.

Wilde's Candle.

The inventor of the well-known Wilde dynamo-electric machine also invented a candle and holder similar in some respects to that of M. Jablochkoff. From his experiments in connection with the Jablochkoff system, Mr. Wilde deduces several very important conclusions, bearing practically upon the question of electric burners of this type. One of the conditions necessary for producing a constant light from the candle, in its most recent form, was that the strength of the alternating current should be such that the carbons consume at a rate of from 4 to 5 inches per hour. If the electric current is too powerful, the carbons become unduly heated, and present additional resistance to the passage of the current. The points at the same time lose their regular conical form. If, on the other hand, the current be too weak, the electric arc plays about the points of the carbons in an irregular manner, and the light is easily extinguished by currents of air.

In the course of his experiments, Mr. Wilde was struck by the apparently insignificant part which the insulating material plays in the maintenance of the light between the carbon points; and it occurred to him to try the effect of covering each of the carbons with a thin coating of hydrate of lime, and mounting them parallel to each other in separate holders, without any insulating material between them. The use of the lime covering was intended to prevent the light from travelling down the contiguous sides of the carbons. On completing the electric circuit the light was maintained between the two points, and the carbons were consumed in the same regular manner as when the separation was by means of plaster of Paris.

Two plain cylindrical rods of carbon, $\frac{3}{16}$ths of an inch in diameter and 8 inches long, were now fixed on the holders, parallel to each other as before, and $\frac{1}{8}$th of an inch apart. The strength of the alternating current was such that it would fuse an iron wire 0·025 in. in diameter and 8 feet in length. On establishing the electric current through the points of the carbons, by means of a conducting paste composed of carbon and gum, the light was produced, and the carbons burnt steadily downwards as in the first trials.

Four pairs of naked carbons mounted in this manner were next placed in series on the circuit of a four-light machine, and the light was produced from these carbons simultaneously, as when the insulating material was used between them. The light from the naked carbons was also more regular than that from the insulated ones, as the plaster of Paris insulation did not always consume at the same rate as the carbons, and thereby obstructed the passage of the current. This was evident from the rosy tinge of the light produced by the volatilisation of the calcium simultaneously with the diminution of the brilliancy of the light from the carbons. The only function, therefore, which the insulating material performs in the electric candle, as shown by these experiments, is that it conceals the singular and beautiful property of the alternating current, to which attention has been directed.

This simple method of burning the carbons will greatly further the development of the electric light, as carbons can be used of much smaller diameter than has hitherto been possible. They may also be of any desired length, for as they are consumed they may be pushed up through the holders without interrupting the light. One of these developments will be a better method of lighting coal and other mines. In this application the alternating currents or waves from a powerful electro-magnet induction machine may be used for generating, simultaneously, alternating secondary currents or waves in a number of small induction coils, placed in various parts of the mine. The light may be produced in the secondary circuits from pairs of small carbons enclosed in a glass vessel, having a small aperture to permit the expansion of the heated air within. Diaphragms of wire gauze may be placed over the aperture to prevent the access of explosive gas. By generating secondary currents or waves, without interrupting the continuity of the primary circuit, the contact breaker is dispensed with, and the subdivisions of the light may be carried to a very great extent.

In the course of his experiments, it was observed by Mr. Wilde that when the electric circuit was completed at the bottom of a pair of carbons close to the holders, the arc immediately ascended to the points, where it remained so long as the current was transmitted. His first impression of this peculiar action of the arc was, that it was due to the ascending current of hot air by which it was surrounded. This, however, was found not to be the cause, as the arc travelled towards the points in whatever position the carbons were placed, whether horizontally or vertically in an inverted position. Moreover, when a pair of carbons was held in the middle by the holders, the arc travelled upwards or downwards to the points, according as the circuit was established above or below the holders. The action was in fact recognised to be the same as that which determines the propagation of an electric current through two rectilinear and parallel conductors submerged in contact with the terrestrial bed, which was described by the same experimenter in the scientific papers of August, 1868.

In all the arrangements in general use for regulating the electric light, when the light is required the ends of the carbon pencils are brought into momentary contact, and are then separated a short distance to enable the light to form between them. The peculiar behaviour of the electric arc when the carbons are placed parallel to each other suggested to Mr. Wilde the means of lighting his carbons automatically, notwithstanding the fact that they could only be made to approach each other by a motion laterally, and to come into contact at their adjacent sides. To accomplish this object, one of the carbon holders is articulated (jointed) or hinged to a small base-plate of cast-iron, Fig. 119, C, which is so constructed as to become an electro-magnet when coiled with a few turns of insulated wire, E. The carbon holder, B, is made in the form of a right-angled lever, to the short horizontal limb of which is fixed an armature, D, placed over the poles of the electro-magnet, E. When the movable and fixed carbon holders are brought into juxtaposition, and the carbons inserted in them, the upper parts of the two carbons are always in contact when no current is transmitted through them, as shown by the dotted lines in the engraving.

The contact between the carbons is maintained by means of an antagonistic spring, inserted in a recess in one of the poles of the electro-magnet, and reacting on the under side of the armature. One extremity of the coil of the electro-magnet is in metallic connection with the base of the carbon holder, while the other extremity of the coil is in connection with the

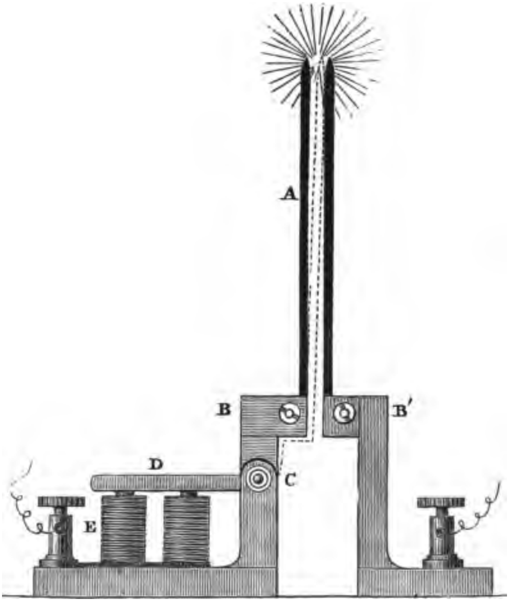


Fig. 119.—Wilde's Candle.

terminal screw at the base of the instrument, from which it is, of course, insulated. The coils of the electro-magnet are thus placed in the same circuit as the carbon pencils.

When the alternating current from a dynamo-electric machine is transmitted to the carbons, the electro-magnet attracts the armature and separates the upper ends of the carbons, which brings them into their normal position, and the light is immediately produced. When the circuit is interrupted the armature is released, the upper ends of the carbons come into contact, and the light is produced as before. When several pairs of carbons are placed in the same circuit, they are by these arrangements lighted simultaneously.

Jamin's Blowpipe Lamp.

A curious application of Mr. Wilde's electric candle has been devised by M. Jamin, who, in a communication to the French Academy of Sciences, gives details from which the following description has been deduced :—Wilde's candle, as just described, consists of a pair of thin carbon-rods separated from each other, the arc forming between them. M. Jamin takes the negative electrode leading from the electrical generator, and, instead of fastening it in the binding-screw at once, makes it describe one or two turns around the candle, from top to bottom, as in Fig. 120, where A is the candle, and the negative electrode is wound one turn round the candle longitudinally, as indicated by the arrows. It will be observed that the direction of the electric arc coincides with that of the outside current. The result of thus arranging the parts is that when the arc is formed it flares up like a gas-flame, being attracted by the passing current. M. Jamin then causes it to impinge upon a cylinder of chalk or lime, as in the lime, or Drummond light. He also employs magnesia. It has the effect of very greatly augmenting the amount of light, and of toning its quality from violet to yellowish green or white by the action of the lime. The heat is so intense as even to fuse the chalk, so that the inventor recommends its use to chemists and others as probably the most powerful flame known. It is, as yet, however, too expensive except upon a small scale. It would appear to be necessary in practice to provide some arrangement to move the lime body downwards to coincide with the receding carbon points. A recent communication from Prof. Samuel Sheldon, of Harvard University, suggests attracting the arc to a point by means of a powerful electro-magnet, and so utilising it as an electric blowpipe.

Fig. 120.—Jamin's Blowpipe Candle.

A further development of this beautiful experiment has appeared in the form of Jamin's candle-lamp. It consists of one or more candles, so arranged as to be each in turn automatically switched into the circuit. The whole is surrounded by several convolutions of insulated wire, so as to cause the diffusion of the voltaic arc in the manner demonstrated in M. Jamin's first experiment. Either the whole or a portion of the current may be caused to circulate in the convolutions of the attracting coil.

De Meritens' Candle.

A device by De Meritens would appear to extend the principle of the electric candle in another direction. This inventor employs a third rod of carbon between the other two, but not in contact with them. It is preferred to have it of half the diameter of the outside rods, and it occupies the place, and partly fulfils the function, of the insulating plaster of Paris or air.

The arc, once produced by any convenient means, plays between the outer rods and the central one, which it consumes. When the arc is thus divided between three rods it has less chance to be extinguished than in Jablochkoff's original candle, and the inventor considers that a smaller current will in this case be necessary to produce an electric light of given power.

Rapieff and Siemens' Candles.

M. Rapieff and Dr. Siemens have produced candle-lamps. Their construction is different from that of Wilde, but the principle and the results are so exactly similar in both cases to that of Wilde that it will be unnecessary to go into details.

Incandescence in Vacuo and Gas.

When a powerful current of electricity is passed through conductors offering considerable resistance, the conductors become heated. If the current be continued, the conductors become white-hot and finally highly incandescent, emitting a light of considerable power. This property of the electric current is frequently shown by lecturers, who use for the purpose a chain composed of alternate links of silver and platinum. The silver being a good conductor, does not easily become heated by the current; but the platinum, having less conducting power, becomes white-hot.

When carbon in the form of graphite is subjected to the passage of a current, its resisting power is so high that it speedily becomes white-hot, and finally incandescent. In this condition it emits a clear white light, but speedily wastes away when exposed to the air. Platinum does not waste so rapidly, but it has other disadvantages, and is more easily fused before the desired condition of luminous incandescence is attained. Many attempts have therefore been made to utilise carbon for the production of electric incandescent light, and enormous difficulties had to be overcome before carbon filaments could be utilised for this purpose.

After repeated trials and failures with incandescent carbon burned in air, it was thought that carbon in the form of thin pencils, enclosed in a glass globe exhausted of air, might, by being rendered highly incandescent by passage of the electric current, afford a permanent source of light, since it was believed that carbon would not burn and waste in vacuo. These attempts, although not few in number or undertaken by unskilled hands, failed in most cases with the early experimenters. So long ago as 1845 an American inventor, Mr. King, patented there and in England a lamp involving this principle. His light was produced in a vacuum, to prevent the oxidation of the incandescent carbon or metal, and was extremely promising for its beauty, brilliancy, and steadiness.

But it failed to be permanent and economical from various defects and deficiencies, some of which have, of course, been removed by recent improvements in the mercury air pumps used for exhausting the bulbs; by the increased power and economy of modern dynamo-electric machines, and by recent advances in the art of subdividing the electric current.

Messrs. Sawyer and Mann, of New York, obtained patents some years ago for a lamp based upon the exhaustion of a glass globe of air, and filling it with pure nitrogen gas, in which the incandescent material is intended to glow permanently. The light is produced by the incandescence of a slender pencil of carbon. The light-giving apparatus is separated from the lower part of the lamp by three diaphragms to shut off downward heat radiation. The copper standards of the lamp are so shaped as to give great radiating surface, so that the conduction of heat downwards to the mechanism of the base is wholly prevented. No detailed description of this lamp will be necessary, further than to say that the electric current enters from below, follows the line of metallic conductors to the burner, thence downwards on the other side to the return portion of the circuit. The light-producing portion is, of course, completely insulated, and also sealed at the base gas-tight.

A fatal defect in all previous lamps depending on incandescent carbon has arisen from what has been called the "vaporising" of the carbon. This Mr. Sawyer holds to be an absurdity, since the carbon is not even fused. The wastage of the carbon in mercurial vacuo and in atmospheres of compound gas is due, he maintains, to chemical decomposition. Many gases, indifferent to carbon at ordinary temperatures, attack it destructively at temperatures obtained in the electric lamp; and the process is continuous, the carbon taken from the burner being redeposited on the glass case, and the gas left free to continue its depredation.

Mr. Sawyer claims to have overcome this difficulty by his method of charging the lamps with pure nitrogen gas only, and by providing for fixing of any residual oxygen left in the lamp. In this way it is claimed that an unwasting carbon is secured. Another stumbling-block, upon which many inventors have come to a standstill, has been the crumbling or disintegration of the carbon burner. This is usually caused by sudden heating when the lamp is first lighted. This was avoided in the earlier Sawyer-Mann lamp by a kind of switch, with the use of which it is impossible to turn all the current on at once, or otherwise than gradually. This, however, the inventor holds, is not the only nor the chief advantage of the switch. It is claimed to be the key to the entire problem of practicable electric distribution.

A dynamo-electric light company has been formed in America to supply lights upon the Sawyer-Mann system, and they claim for it the following advantages:—It is well known that an electric current will exactly and readily divide among circuits of equal resistance; accordingly, if the resistance of a sub-circuit be maintained constant, no matter what may be going on in it, whether a lamp is not lighted at all or lighted to a mere taper, or to any intermediary stage up to full brilliancy, it is obvious that no other lamps in circuit will be affected.

The greater part of the illumination produced on this system is the product of a small part of the current. When the light is well on a very slight increase in the current increases the light enormously. It is here that the great loss occasioned by dividing a fixed current among several lamps finds its explanation.

A current that suffices in one lamp to produce a a light, say, of 100 candles, will, if divided between 2 lamps, give in each, perhaps, no more than 20 candles, or even 10, making a loss of 80 candles in the sum total. But if the current be doubled, each lamp will give a light of 100 candles, and the sum total will be two hundred candles instead of 20. Having brought a carbon lamp or a system of such lamps up to the point of feeble incandescence, a (proportionally) small addition to the current will make them all brilliant. If at 6000° Fahr. a given carbon will produce a light of 3 candles, at 12,000 Fahr. it will give 9 candles, and at 24,000° Fahr. it will give 81 candles; the illuminating power increasing with vastly greater rapidity than the temperature.

When the main is tapped for a sub-circuit, a shunt is introduced so as to throw so much of the current as may be needed into the derived circuit. The resistance of, say, 100 added lamps will be about 1,000 ohms. By giving to the shunt a resistance of 10 ohms, 100th of the current will be diverted, and the lamps supplied. Where a large number of lamps are required in a circuit, a combination of two plans indicated is employed. The diversion of any portions of the electric supply into an added circuit, whether one house or a group of houses, necessarily increases the aggregate resistance of the electric district, and calls for more work from the generator. To meet such contingencies automatically, Messrs.

Sawyer and Mann have invented and patented a regulator, which responds instantly to any increase or diminution in the demand, thereby securing an absolutely uniform volume of current.

This system does not appear to have had an extended trial, and it is doubtful whether the carbon pencils will be perfectly permanent. The light obtained by incandescent pencils is much less than that from the open arc with the same current, and the incandescent lamp is in this respect costly, even although a perfectly permanent pencil-lamp could be obtained. There is an obvious defect, too, in the Sawyer-Mann system when the resistance of the circuit, and consequently the expenditure is always the same, whether the lamps are burning or not. This could, no doubt, be obviated.

M. Fontaine has likewise made many experiments with carbon pencils, but the best of them were consumed as usual in air in 15 minutes. Konn has also invented an incandescent lamp, in which a vacuum is maintained. Other inventors have also produced lamps of little use in practice.

Edison's First Lamps.

Mr. Edison's first experiments with the electric incandescent lamps, when regarded from the standpoint of conspicuous success he has now attained, are so full of interest that it will be well to retain the account of them given in this chapter in the first and second editions of the book.

Edison's first lamp (Fig. 121) was based upon a very old idea—the incandescence of platinum, which was employed by various inventors, and by King as early as 1845. All such lamps have so far been failures, and have proved wasteful of current, inasmuch as the true arc gives much more light for the same expenditure of power in the circuit; but the worst defect was undoubtedly the unstable nature of the lamp. Edison's device, however, depended almost altogether for its usefulness upon an automatic regulator attached to it, and it has proved that automatic apparatus of this class work very indifferently. He employed, first, a strip of an alloy of platinum and iridium, A. This is fastened between two holders, the lower one of which is a lever, B, jointed at one end. This lever is provided with a spiral spring, D, constantly stretching the platinum-iridium strip, and under its end is a contact point, C. When the current passes the strip is made white hot, and gives out considerable light before it fuses. The expansion consequent upon this allows the antagonistic spring to put the strip out of circuit for an instant when it is in danger of being fused by the strength of current. Unfortunately, however, the expansibility of platinum is extremely small, and although the lever provided multiplies the expansion into a considerable movement, the platinum-iridium strip is very often fused before it can act. It is, in fact, extremely doubtful whether any regulator of current upon this principle will ever be devised.

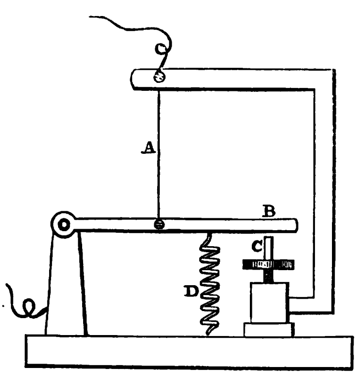


Fig. 121.—Edison's Experimental Platinum-Iridium Lamp.

It must not be forgotten, also, that any contact points in the circuit of a dynamo-electric machine will never work well. There is a powerful discharge of stored-up electric energy as soon as the circuit is broken, and what contact points will withstand such sparks? If there is to be regulation of current at all, it must be by means of some substance upon which pressure acts to increase or decrease the resistance, and not by open contact. It is, in short, at once apparent that the obstacles which stand in the way of inventing a useful lamp on this system are of a kind difficult of removal. The expansion of this lamp itself when it becomes heated will suffice to render useless any contacts or adjustments previously made. The apparatus is too delicate, and may be said to be useless in any but skilled hands. This idea of regulating the current has been tried in various pieces of apparatus intended to automatically govern the circuit of a dynamo-electric machine, and which are here spoken of under "Regulators of Current," p. 184.

Edison's first lamp was tried in England, but the results were anything but satisfactory, considering that it was originally intended to be applicable to general household purposes.

From private experiments made with Edison's apparatus, and modifications of it, the greatest care was found to be necessary to prevent the instant melting of the incandescent strip, and if the regulator is not adjusted with the greatest accuracy, the strip disappears under the energy in a twinkling.

Mr. Edison has also employed lamps made with platinum wire spirals, regulated again by expansion, and a break in the circuit. He also proposed the use of secondary currents, induction coils, and secondary batteries in circuit. Now known as transformers.

With regard to the platinum-iridium spirals for use in Mr. Edison's experimental lamps, a communication by the inventor himself, read before the American Association for the Advancement of Science, contains some interesting particulars of a new method by which they may be prepared for use in electric lamps.

In the course of his experiments on electric lighting he has developed some striking phenomena arising from the heating of metals by flames and by the electric current, especially wires of platinum, and platinum alloyed with iridium. The first fact observed was that platinum lost weight when treated in a flame of hydrogen, that the metal coloured the flame green, and that these two results combined until the whole of the platinum in contact with the flame had disappeared. A platinum wire, 20,000th of an inch in diameter, was wound in the form of a spiral one-eighth of an inch in diameter and half an inch in length. The two ends of the spiral were secured to clamping-posts, and the whole apparatus was covered with a glass shade. Upon bringing the spiral to incandescence for 20 minutes, that part of the globe in line with the sides of the spiral became slightly darkened; in five hours the deposit became so thick that the incandescent spiral could not be seen through the deposit.

This film, which was most perfect, consists of platinum, and Mr. Edison has no doubt but large plates of glass might be coated economically by placing them on each side of a large sheet of platinum, kept incandescent by the electric current.

This loss in weight, together with the deposit upon the glass, presented a very serious obstacle to the use of metallic wires for giving light by incandescence; but this was easily surmounted after the cause was ascertained. He coated the wire forming the spiral with the oxide of magnesium, by dusting upon it finely powdered acetate of magnesium. While incandescent the salt was decomposed by the heat, and there remained a strongly adherent coating of the oxide. The spiral so coated was covered with a glass shade and brought to incandescence for several minutes; but instead of a deposit of platinum upon the glass, there was a deposit of the oxide of magnesia. From this and other experiments Mr. Edison became convinced that this effect was due to the washing action of the air upon the spiral; that the loss of weight and the coloration of the hydrogen flame was also due to the wearing away of the surface of the platina, by the attrition produced by the impact of the stream of gases upon the highly incandescent surface, and not to volatilisation, as commonly supposed.

He further describes other and far more important phenomena observed in his experiments. If a short length of platinum wire, 1,000th of an inch in diameter, be held in the flame of a Bunsen burner, at some part it will fuse and a piece of the wire will be bent at an angle by the action of the globule of melted platinum; in some cases there are several globules formed simultaneously, and the wire assumes a zigzag shape. With a wire 4,000th of an inch in diameter this effect does not take place, as the temperature cannot be raised to equal that of the small wire, owing to the increased radiating surface and mass. After heating, if the wire be examined under a microscope, that part of the surface which has been incandescent will be found covered with innumerable cracks. If the wire be placed between clamping-posts, and heated to incandescence for 20 minutes by the passage of an electric current, the cracks will be so enlarged as to be seen with the naked eye; the wire under the microscope presents a shrunken appearance, and is full of deep cracks.

If the current is continued for several hours, these effects will so increase that the wire will fall to pieces. This disintegration has been noticed in platinum long subject to the action of a flame, by Professor Draper. The failure of the process of lighting invented by the French chemist, Tessié-du-Motay, who raised sheets of platinum to incandescence by introducing them into a hydrogen flame, was due to the rapid disintegration of the metal. Mr. Edison has ascertained the cause of this phenomenon, and has, he says, succeeded in eliminating that which produces it, and in doing so has produced a metal in a state hitherto unknown, and which is absolutely stable at a temperature when nearly all substances melt or are consumed; a metal which, although originally soft and pliable, becomes as homogeneous as glass and as rigid as steel. When wound in the form of a spiral, it is as springy and elastic when at the most dazzling incandescence as when cold, and cannot be annealed by any process now commonly known. For the cause of this shrinking and cracking of the wire is due entirely to the expansion of the air in the mechanical and physical pores of the platinum, and the contraction upon the escape of the air. Platinum, as sold in commerce, may be compared to sandstone, in which the whole is made of a great number of particles with many air spaces. The sandstone upon melting becomes homogeneous, and no air spaces exist. With platinum or any metal the air spaces may be eliminated and the metal made homogeneous by a very simple process.

This process is then described by Mr. Edison. He made a large number of platinum spirals, all of the same size and form and the same quality of wire; each spiral presented to the air a radiating surface of $3\frac{1}{16}$ of an inch; 5 of these were brought by the electric current up to the melting-point, the light was measured by a photometer, and the average light was equal to 4 standard candles for each spiral just at the melting-point. One of the same kind of spirals was placed in the receiver of an air-pump, and the air exhausted to 2 millimètres; a weak current was then passed through the wire to warm it slightly, for the purpose of assisting slightly the passage of the air from the pores of the metal into the vacuum. The temperature of the wire was gradually augmented at intervals of ten minutes until it became red. The object of slowly increasing the temperature was to allow the air to pass out gradually and not explosively; after which the current was increased at intervals of fifteen minutes. Before each increase in the current the wire was allowed to cool, and the contraction and expansion at these high temperatures caused the wire to weld together at the points previously containing air. In one hour and forty minutes this spiral had reached such a temperature without melting that it was giving a light of 25 standard candles, whereas it would undoubtedly have melted before it gave a light of 5 candles had it not been put through the above process. Several more spirals were afterwards tried, with the same result. One spiral which had been brought to these high temperatures more slowly gave a light equal to 30 standard candles. In the open air this spiral gave nearly the same light, although it required more current to keep it at the same temperature. Upon examination of those spirals which had passed through the vacuum process, by the aid of a microscope, no cracks were visible; the wire had become as white as silver, and had a polish which could not be given it by any other means. The wire had a smaller diameter than before treatment, and it was exceedingly difficult to melt in the oxy-hydrogen flame as compared with the untreated platinum. It was found that it was as hard as the steel wire used in pianos, and that it could not be annealed at any temperature. His experiments with many metals treated by this process have proved to his satisfaction, and he has no hesitation in stating, that which is known as annealing of metals to make them soft and pliable is nothing more than the cracking of the metal. In every case where a hard-drawn wire had been annealed, a powerful microscope revealed myriads of cracks in the metal. Since the experiment just mentioned was made, further investigations, with the aid of Sprengel mercury pumps, produced higher exhaustions, and by continuing the exhausting for five hours and intermitting the current a great number of times, the result is stated to be the light of 8 standard candles from a spiral of wire with a total radiating surface of $\frac{1}{16}$th of an inch, or a surface about equal to a grain of buckwheat. With spirals of this small size which have not passed through the process the average amount of light given out before melting is less than one standard candle.

Edison claimed to having obtained 8 separate lamps, each giving out an absolutely steady light, and each equal to 16 standard candles, or a total of 128 candles, by the expenditure of 30,000 foot-lbs. of energy, or less than one horse-power. As a matter of curiosity he made spirals of other metals, and excluded the air from them in the manner stated. Common iron wire may be made to give a light greater than platinum not treated. For reasons stated further on Edison abandoned the use of metallic conductors for the incandescent portion of the lamp.

Up to December, 1879, the outcome of Mr. Edison's praiseworthy labours to obtain a constant burner by electric agency, was a small lamp in the form of a glass globe exhausted of air, and containing in the electric circuit a horseshoe-shaped strip of carbonised cardboard.

This horse-shoe was stamped from "Bristol board," and was then placed in a wrought-iron mould and raised to such a temperature that the volatile constituents of the paper were driven off, the result being a miniature horse-shoe (2 in. long) composed of carbonised paper. Through this, when the containing globe had been exhausted by the air-pump, the current was passed from pole to pole by connections of platinum wire. It was claimed that this substance, which became highly incandescent and yielded a brilliant light, was unchangeable by heat in vacuo, and that a lamp could be produced at an outlay of 25 cents.

A number of these lamps were seen burning in the inventor's laboratory by correspondents of the press, English and American, during the month of December, 1879. The result was stated to be so satisfactory that

Mr. Edison intended to illuminate, on a practical scale, the village of Menlo Park, and then to extend the system to New York.

There was little probability, however, that this lamp would prove constant. Carbonised paper in various forms had been repeatedly tried before, and it is probably not constant in the best possible vacuum obtainable.

Swan's and Edison's Lamps.

General description of the Glow Lamp.—It has been said that carbonised paper had been tried as an incandescent burner before Mr. Edison employed that substance. Amongst others who had experimented in this manner was Mr. J. W. Swan, of Newcastle-on-Tyne, and it appears that both Mr. Swan and Mr. Edison were engaged simultaneously upon the same problem, with the same materials — carbonised paper—about the end of 1879.

Mr. Swan, after many experiments, appears to have first abandoned the use of carbonised paper, and to have resorted to cotton or linen thread, treated with dilute sulphuric acid, and afterwards carbonised in a closed crucible at a white heat. The result of Mr. Swan's experiments was a hard and elastic filament of pure carbon about 3 inches in length. It is made to describe a single convolution, and its extremities are connected to two platinum wires. The filament is then inserted into a small glass globe, from which the air is extracted by long continued action with mercury air pumps. When the highest attainable vacuum is obtained, the connection with the interior of the globe is fused up, the result being the arrangement exhibited in Fig. 122. The platinum wires terminate in two small loops as represented. These are readily attached to or removed from the electrical connections of a small ebonite socket, shown in Fig. 123. The spiral spring represented serves to receive the base of the globe, and to press the lamp away from its socket, so that the metallic contact between the loops in Fig. 122 and the two small hooks in Fig. 123 may be as perfect as possible. The carbon thread or wire employed by Mr. Swan is as elastic as steel, and is considerably thinner than the black line shown in the diagram. When the current passes the carbon wire becomes incandescent and emits a beautiful white, silent, and steady light. The vacuum attained in the lamp is so perfect that, instead of being wasted away, the filament becomes more dense by use. In course of time, however, there appears to be a gradual wasting away of the carbon wire at the positive end, and probably an increase of diameter, at the negative extremity. If the current is much too strong, the lamp may be destroyed in a very short time; but if the current is only a little over the normal strength used for the lamp, a disengagement of the particles composing the carbon wire ensues, and in the course of time the interior of the globe may present a smoked appearance. This agrees with the results of Mr. Edison's experiments with the platinum spirals. When the lamp is worked by the current suited to its powers, the "life" of

Fig. 122.—Swan's Lamp.

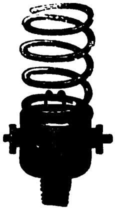


Fig. 123.—Socket for Swan's Lamp.

the carbon wire varies from 700 to perhaps 3,000 hours. Hence, a lamp of this description may serve for ordinary purposes for many months, or a year, burning nightly. The "life" of the lamp varies, however, to a great extent; and it is difficult, if not impossible, to assign a limit, with any show of reason, to the time one of the carbon loops may last. When alternating currents are used it is probable that, since there will result no wasting away at either extremity, the "life" of the carbon loop may be considerably extended. The cost of the lamp is very small. They are made of from 5 to 100 candle power, according to the length of the carbon loop employed. The 18-candle power lamp, is, however, the most generally useful. The resistance of this lamp is about 150 ohms when hot, when cold it is considerably greater, probably 250 ohms. These lamps are now a regular article of commerce. They are adapted for fitting to existing gas-brackets. One insulated wire being led to the lamp, the return may be effected through the gas-fittings if required. Swan's lamps have been in constant use at the Savoy Theatre, London, since the end of 1881. About 1,158 of these lamps have since that time been used to illuminate the whole of the auditorium and the stage in this installation, of which further particulars are given farther on.

Detailed Account of the Incandescent Lamp.

Several patents for incandescent lamps were taken out by Edison, Swan, Sawyer, Man, and others during the years 1878, 1879, and 1880. The most remarkable of these appears to be that of Edison of November 10, 1879 (No. 4,576).

The Earlier Filaments.—This specification points out several of the more essential conditions upon which the success of incandescent lamps depend. It begins by stating that for lamps in multiple a high resistance of the filament is imperative. This condition had, however, been partially fulfilled in Edison's platinum and iron wire lamps, in which the filament or wire was intended to have a coating of some "infusible" earth. All the wire lamps were abandoned, however, and the object of the inventor was to produce a lamp with a filament as nearly as possible permanent and *offering high resistance with the minimum of radiating surface.* Carbon in the graphite form had long been known (since 1845) to withstand the most intense heat of electricity in vacuo better than any other substance, and many attempts were made by both Edison and Swan, during 1879, to obtain a sufficiently thin wire or conductor of this material. The patent specification under review then goes on to state that such a filament of the graphite form of carbon could be obtained by *carbonising cotton thread*, any fibrous vegetable substance which will have a carbon residue after heating in a closed chamber, such fibrous substance coated with a compound of lamp-black and tar, or a compound of tar and lamp-black, in the form of putty.

Edison's experiments with these materials do not, however, appear to have yielded the substance required, and a subsequent patent (1880, No. 3,765), mentions particularly the hard, glossy exterior of bamboo cane as being adapted, after minute subdivision, for the production of the carbon filaments. Various grasses were also used in the production of filaments about this time. It was thought in the beginning of the year 1880 that a necessary condition of the raw material was its having a fibrous or natural structure, but subsequent discoveries have disproved this.

Attachment of Filaments.—In most of the patent specifications that have appeared relating to incandescent lamps, the various processes of attaching the filaments to the conducting wires are minutely described. At first this was a weak point in most of the lamps, and Mr. Swan avers that his chief difficulty in the production of a carbon lamp in 1879 was that of mounting the pencil or filament in electrical contact with the platinum conductors. This difficulty was got over, first by electro-plating or depositing copper around both carbon and wire while in contact, and by moulding the end of the carbon filament around the extremity of the wire. Subsequently it has been accomplished by carbonising some fresh carbonisible material, such as tar and lamp-black, around filament and wire by means of heat. Also by making the platinum wire into a spiral tube, inserting the end of the filament, and affixing the whole by means of a carbon cement, fixed by heat, and by other methods too numerous too mention.

"*Flashed*" *Filaments.*—The lamps produced in 1879 and the beginning of 1880 had but a short life. Very few of them would burn for fifty hours without breakage of the filament. This was discovered to be due to two defects of peculiar interest.

First, it was found that the most perfect filaments it was then possible to produce, although apparently of uniform cross-section, exhibited under the heating of the current *bright and dull portions*, proving a variation of structure or size. Thus, the bright portions had more than their share of the current, and gave way in consequence. Several years before carbon filament lamps were thought of, a French chemist, M. Duprez, in experimenting on the reduction and volatilisation of carbon, discovered that when carbon was heated in an atmosphere of hydro-carbon, a deposit of an extremely dense form of solid carbon occurred. But it was noticed in M. Deprez's publication that this tendency hindered certain experiments, and was really an obstruction to the aims of the chemist, whose experiments had no reference to electric lamps.

Messrs. Sawyer and Man (1878, No. 4,847, Cheesborough) took out a patent for the application of this fact to the perfecting of carbon pencils for incandescent lamps. They noticed that when a glowing pencil was immersed in a heavy hydro-carbon gas or liquid, a deposit of graphite took place, and that it *occurred more particularly upon those portions of the carbon that has most heat*, that is, the *thinnest portions*. The result of subjecting a pencil of varying diameter to this process was that it tended to become of uniform diameter, and thus in a beautiful way corrected its own defects.

This process of "flashing" carbons was tried upon filaments with the most gratifying results, and has been largely used in the commercial production of lamps, it being essential that the filament should glow with equal intensity throughout.

"*Running on the Pumps.*"—After constructing and exhibiting various incandescent lamps, more chiefly from pencils and "horse-shoes" of carbon enclosed in a glass globe exhausted of air, Mr. Swan took out a patent (on January 2, 1880) for a process of improving the condition of the vacuum. Finding that although the Sprengel mercury pump exerted its full effect upon the vacuum, there was still evidence of the attacks of oxygen upon the filament or pencil after passing the current, Swan conceived the idea that some gas must be left in the substance of the carbon itself, that might not be removed by the Sprengel pump. Thereupon, it occurred to him to pass the current through the lamp and render it incandescent *while yet attached to the vacuum pump.* The theoretical idea was no doubt that by setting the substance of the filament into a state of electrical vibration, any possible enclosure of gas might thereby be set free. Surprising results followed the discovery of this method of "running" the lamps while attached to the pump, and it has been adopted by most makers of lamps.

Parchmentised Cotton Carbons.—Mr. Swan took out another patent (January 20, 1880) for a carbon "horseshoe" or "hair-pin," composed of paper or cardboard "parchmentised" by treatment with sulphuric acid, and thereafter carbonised to the graphite state. It was difficult to obtain carbons from this material of sufficient thinness, resistance, and resiliency, and Swan took out another patent (November 27, 1880) for parchmentised and carbonised cotton thread filaments for incandescent electric lamps. This patent marked a great step in advance, and the success of the new filaments was decisive and conspicuous. The "life" of an incandescent lamp might now have been reckoned at 1,000 hours.

The Process of Carbonising.—It is claimed in more than one of the patent specifications relating to carbons that the slender filaments of bamboo, grass, cotton, linen, &c., might be carbonised by enclosing in an iron or unporous clay vessel, enclosed from the air and heated to a high temperature. Many scientific persons called this statement in question and declared that if there was a sufficiency of air within the vessel the filaments must inevitably be burned to ash. Many experiments tended to strengthen this impression. It has been known to chemists and others that to carbonise without destroying slender articles of a vegetable nature, the only safe way was to pack them carefully, surrounded by a large body of some such substance as charcoal, finely powdered, and in an iron box carefully luted with fireclay. Filaments placed by themselves in the charcoal are liable to distortion, so that, before carbonising, they are usually wound or placed upon a shape, former, or frame of carbon, wood, or other substance. The heat is applied very gradually, and is sometimes kept up for 12 and 14 hours. The mean diameter of the filaments after carbonising may be taken at ·150 of a millimeter.

The Cellulose Filament.—The dimensions and structure of the necessary carbon conductors for incandescent lamps having been once settled upon, various methods for their manufacture began to be published, and no doubt many lamps are made by processes kept secret. The nature of the filaments made by one manufacturer was described by Mr. Sellon, before Mr. Justice Kay, as follows.* Cotton wool is dissolved in chloride of zinc, and being slightly heated the result is a viscous semi-liquid substance, resembling in appearance a strong solution of gum-arabic. This is boiled in the receiver of an air pump to extract all air; then it is forced through a die or small orifice by the pressure of a head of mercury, and the filament so

---

* "Edison & Swan Electric Light Co. *v.* Holland and others," July, 1888.

formed is received in a vessel of alcohol, and solidifies in the form of a thread. It is then left for a time in another vessel of alcohol which dissolves all impurities, and leaves it a non-structural thread of cellulose in an extremely pure condition. It is dried and carbonised and fitted for use in the lamp.

The Platinum Conductors.—Were it not for a simple scientific fact that the rate of expansion under heat is nearly the same for glass and platinum, it might be impossible to construct a vacuum lamp of the kind under notice. This enables the lamp maker to seal the platinum wires through the base of the lamp and to produce a joint that will withstand the highest attainable vacuum. But the ratio is not quite the same, and, moreover, glass being an indifferent conductor of heat, numerous failures of lamps, especially lamps of high candle-power emitting much heat, took place in the earlier days of the bulbs. It was found that a single platinum wire for each end of the filament led to frequent failures or cracking of the glass. This would no doubt be due to the superior temperature of the platinum. Latterly, therefore, the platinum conductors are divided into two or more branches, or thin wires.

Life, Efficiency, and Economy of Incandescent Lamps.

The fact that the "life" of a glow lamp depends almost entirely upon the temperature at which it is maintained alight, has given rise to a great deal of controversy in electrical circles as to the most economical temperature or candle-power at which "run" the lamps. This will be seen to be a question of great interest and import, when we consider that the higher the state of incandescence the lower the cost of the light; in other words, if the electrical power expended upon the lamp is increased, its light is more than in proportion to the power (the light-giving effect is said to vary approximately as the fifth power of the electro-motive force at the lamp terminals); but the life of the lamp is shortened. We need not enter more deeply into the question here, mainly because the conditions of the production (the cost) of both electricity and lamps are daily undergoing modification, and calculations made in 1889 would probably not apply to 1890.

High Candle-power Incandescent Lamps.—The efforts of inventors of glow lamps were, until about the year 1885, chiefly devoted to the perfecting of filaments having about fifty ohms resistance, and capable of withstanding a "glow" of about 16 candle-power for general lighting, to take the place of jets of gas. At the exhibition held at Newcastle-on-Tyne, in 1887, the Hon. Charles Parsons showed specimens of high candle-power glow lamps, ranging from 50 candle-power to 1,000 candle-power. These "sun-beam" lamps are provided with a long and thick carbon conductor.

There is a certain advantage in employing a single lamp of high candle-power, rather than a group of small lamps, to illuminate any given point, and the lamps are less costly to instal and maintain. For example, a 200 candle-power lamp gives a light equalling twelve or thirteen lamps of 16-candle power, but costs only twice as much as one 16 candle-power lamp. A high candle-power lamp giving 1,000 candle-power will cost less than ten 16 candle-power lamps.

Number of lamps per horse-power upon dynamo.—

With a dynamo of high efficiency about 12 lamps of 16 candle-power might be maintained per horse-power, but 10 and even less is more likely to be the number in actual practice. It depends partly, as stated below, upon the number of watts per candle. More lamps could be maintained at 5 watts per candle than at 4.

It may be of interest to show the candle-powers and corresponding voltage, &c., of the leading incandescent lamps:—

APPROXIMATE VOLTS AND CURRENT OF THE VARIOUS CLASSES OF EDISON-SWAN LAMPS.

		Volts.	Ampères.		Volts.	Ampères.	Tariff Price List. s.	d.
1 Candle-power	from about	3	·8	to about	8	·3		
2½ ,,	,,	5	1·4	,,	25	·45	3	9
5 ,,	,,	5	3	,,	65	·35	3	9
8 ,,	,,	10	2·8	,,	120	·3	3	9
16 ,,	,,	15	3·7	,,	160	·4	3	9
25 ,,	,,	40	2·2	,,	120	·7	4	0
32 ,,	,,	50	2·3	,,	120	·9	4	0
50 ,,	,,	50	3·5	,,	120	1·4	5	0
100 ,,	,,	50	7	,,	120	2·9	7	6
Micro and Miniature Lamps	,,	3	·8	,,	8	·3		
200 Candle-power	,,	80		,,	105		10	0
500 ,,	,,	80		,,	105		17	6
1,000 ,,	,,	80		,,	105		30	0

All lamps taking less than ·9 ampère are marked at 4 watts per candle, and all lamps taking more than ·9 ampère at 3·5 watts per candle.

Continuous and alternating currents for glow lamps.—It has been shown that, under the influence of a current in one direction, the filaments in lamps exhibited a thinning away at one extremity, and usually broke there—the extremity connected with the positive pole from the dynamo. It is claimed for the alternating current that this gradual and partial attenuation does not occur, or, at any rate, that it is uniform for both extremities of the filament. Any "wastage" of the filament is found to become firmly deposited upon the interior surface of the surrounding glass bulb, giving it a smoked appearance. When a glow lamp is served with too great a current, its light rapidly acquires the blueish tint of the arc, and the breakage of the filament follows as a matter of course. Lamps served with a constant voltage and current last much longer than those in circuits where variations occur. At the figures given in the above table, where the conditions are fairly constant, glow lamps have an average life as high as 1,000 hours, although instances of lamps having burned 5,000 hours are becoming common.

The neck of Edison's lamp carries a metallic screwed plug, intended to fit into a socket. This portion communicates with one of the platinum wires. The other wire is connected to a central metal stud, insulated from the collar. When the arrangement is screwed into its socket, contacts are made with the necessary leading wires. A circuit-interrupting key is provided, by means of which the circuit may be closed or opened at will. Fig. 124 represents Edison's lamp about half real size. In all other respects Edison's lamp is similar to Swan's. It is made in several different light-giving powers, but the lamp in general use at present is intended to yield a light of 16 candles, so that it may be made to take the place of ordinary gas jets. The resistance of this lamp when cold

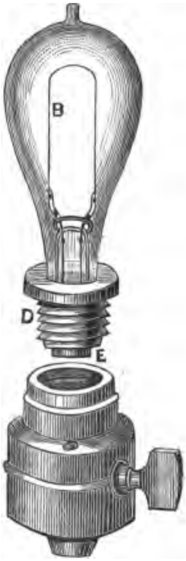


Fig. 124.—Edison's Lamp.

is 220 ohms. When hot it is reduced to 140 ohms.

Mr. St. George Lane Fox has also invented an incandescence electric lamp similar in design to that of Edison. Mr. Fox employs a carbon wire made from flax or cotton thread, also the root of the grass known as "French whisk." When carbonised, this thread is mounted, and rendered incandescent in coal-gas and benzoline,[*] which completes the carbonisation. The glass bulbs are carefully exhausted by means of mercury pumps.


Fig. 125.—Maxim's Lamp.

Mr. Maxim, of New York, was among the first who employed carbon in the form of a filament for incandescent lighting, and his lamps have been in extensive use. In this case the filament is formed into a shape like the letter M. Fig. 125 represents Mr. Maxim's lamp, which is in other respects similar to those of Edison and Swan.

Several other inventors have produced incandescent lamps. Many modifications of those already described have been published. One inventor forms a hollow carbon filament or tube by depositing carbon upon a fine wire of platinum, and deflagrating the platinum. Another deposits carbon upon an infusible insulating filament.

Miner's Electric Safety Lamps.

The Clanny miner's oil lamp yields a light of about half candle-power only, and it has been found that with the increased velocity of the ventilating currents

---

[*] "Flashing," see p. 285.

in mines introduced of late years, such lamps are troublesome and unsafe. Many attempts have been made to press electricity into the service of the miner for illuminating purposes. It was at first thought feasible to run electric mains in the workings, as permanent fixtures, and to attach portable glow lamps to these by means of flexible conductors of sufficient length to allow of the lamp being carried about. But it was speedily found that such a system could not be made free from danger in a "fiery" mine; nor indeed would it be practicable in any mine, according to the opinion of experts.

In the year 1881 Mr. Swan effected a partial solution of the problem by the introduction of a secondary battery, made in portable form, and carrying, affixed to the case, a very small incandescent lamp. This arrangement was a great improvement upon the old oil lamps, inasmuch as it yielded a light four or five times more powerful, and from the nature of the incandescent filament necessarily quite a safe lamp.

Various inventors followed with lamps fed by both primary and secondary batteries. Considerable experience has thus been acquired in the production of a suitable lamp, and the question may now be considered as satisfactorily solved. There is still one little drawback—the weight, which in the average is rather greater than that of the older oil lamps. But the large numbers of such lamps in use at the chief mines, and the rapidity with which they are being introduced, would appear to indicate their entire suitability. It is, moreover, quite certain that the miner himself considers the new lamp a great boon.

Swan's Miner's Lamp.—The elements consist of a secondary or accumulator battery of four cells, formed of hard rubber, containing each a pair of cylindrical and concentric packed lead plates prepared after the manner of the latest type of accumulator battery (p. 44, &c.). The whole is properly connected in series and enclosed in a wooden case. The liquid is the usual dilute acid. The incandescent lamp is attached to one side of the case, and is protected by a strong convex lens. The whole weighs seven pounds. The price is very moderate. The average light is from one to one and a half candle-power, maintained for ten hours. Recharging of the battery occupies about twelve hours. It is effected by having connections from the poles attached to the sides of the case of each lamp, so that a line of lamps, placed between two conductors from the dynamo upon a suitable table, are charged at once. This method of merely placing the lamps upon the charging table and charging them in "banks" has proved very successful. The cost of running is merely nominal. The cost of renewals of plates and lamps will prove the main consideration. Some of the makers of such lamps estimate the life of the battery at two years. The lamps themselves may run an average of a thousand hours.

Pitkin's Miner's Lamp.—This lamp yields a light of four or five candles. It is run by a secondary battery of four cells, yielding an E. M. F. of 8 volts and about ·5 ampère. The plates in the cells are flat, two in each cell. The battery will maintain the lamp for five or six hours, and in charging takes about eight hours. The whole is enclosed in a wood case, as in Swan's lamp, and weighs eight pounds. In one form of the lamp the glow-bulb may be detached (with its reflector) and carried about by means ot a flexible conductor. This lamp is furnished with a resistance switch to enable the user to divert a portion of the current if too powerful for the filament when the accumulator is freshly charged.

Schanschieff's Miner's Lamp.—This lamp is maintained by a portable primary battery, and that portion of it is necessarily lighter in weight than the accumulators used in other lamps. The plates are of zinc and carbon, after the manner of the bichromate battery (p. 11). The excitant is a solution of the sulphate (basic) of mercury prepared in a manner patented by the inventor. The consumption of zinc is half a pound for forty-eight hours run upon the lamp. The excitant is usually supplied in quantity where the lamps are used, and costs 5s. per gallon. The battery is charged with about twenty ounces of the solution, and runs about eight hours. In recharging the spent liquid is run off, the cell rinsed out, and fresh solution supplied. The spent liquid is said to be worth after-treatment for mercury. The weight of the complete lamp is four and a half pounds, the light yielded from one and a half to two candle-power. The price is moderate, and such primary battery-lamps will probably commend themselves where dynamos are not already upon the ground for recharging purposes. In one form of the portable lamp it is swung upon trunnions, and so arranged that when turned upside down the liquid is withdrawn from the plates, so putting out the light.

CHAPTER X.

ON ELECTRICAL DISTRIBUTION.

DISTRIBUTION of electricity for lighting purposes is carried out under several different systems. But the particular class of mains and auxiliary circuits employed are altogether dependent upon the class of currents to be distributed. As we have ascertained, in reference to the nature of the generating machinery, the two leading branches are,

1. THE CONTINUOUS UNI-DIRECTION CURRENT.
2. THE ALTERNATING OR BACK-AND-FORTH CURRENT.

No. 1 is usually associated with low tension, seldom above a few hundred volts, and is frequently used in conjunction with a distributing or storage system of secondary batteries or accumulators.

No. 2 is usually distributed at a high tension, frequently some thousands of volts, and is generally associated with "tension reducers" or transformers, situated at the root of house-circuits, so that the tension upon the lamps is seldom above a hundred volts.

The former appears suitable for distribution in a restricted area—say within a radius of a mile of the generating station.

The latter appears suitable for distribution within a radius of many miles of the central station. Each system has powerful advocates. The first is supported by the names of Crompton,* Preece, Hopkinson, Edison, and others.

The alternating system is advocated by Ferranti, Swinburne, Snell, Mordey, Kapp, and many others.

As may be expected, each system calls for a distinct class of main and auxiliary circuits for distribution purposes. The direct current system elects to effect the distribution—1. By simple circuit, suitable for arc lamps in street lighting, or for short distances in incandescent lighting, long known and developed chiefly by Siemens and Brush. 2. Distribution for incandescent lighting over extended areas by a system (developed by Edison) of feeders; 3. Or distribution over extended areas by means of storage or accumulator batteries (developed by Crompton, Parker, and others).

The alternating current system appears at first to be much simpler. The distribution is effected chiefly from a pair of high tension mains, working through transformers, producing low tension currents within buildings. The system of distribution by transformers was developed chiefly by Gaulard and Gibbs, Kapp and Snell, Ferranti, Westinghouse, and others.

Broadly speaking, the systems of distribution in general use, with special reference to conductors conveying the current, may be divided as follows:—

THE SERIES SYSTEM—*Arc Lighting.*
THE TWO-WIRE SYSTEM—*for Incandescent Lamps.*

---

* See Paper, *Transformers* v. *Accumulators*, read before the Institution of Electrical Engineers, April 12, 1888.

THE TWO-WIRE SYSTEM WITH FEEDERS.
THE THREE-WIRE SYSTEM.

These may be regarded as *main* systems, conveying the electricity to the outer walls of buildings to be served. Within the walls of buildings the system of distribution to the lamps is much the same, but it is common to term the wiring of the building as having been carried out upon

The Multiple Arc System, or
The Multiple Series System.

As the multiple arc system provides for only one lamp to bridge across the two wires, certain requirements and advantages attend it, *i.e.* the volts must not much exceed a hundred, and if one lamp breaks none of the others are affected.

The multiple series system implies the use of two or more lamps bridging across the two wires, and calls for a potential frequently much over a hundred volts; but it has the disadvantage that if one of the lamps bridging the wires were to break, the companion lamp or lamps upon that particular bridge would be extinguished. It would appear that to the "secondary-battery-transformer" system, since it is advisable to pass a considerable number of volts—say two hundred—into the building, the multiple series system would be peculiarly suitable.

Distribution within buildings is also frequently carried out upon the three-wire system, of which further particulars are given further on.

In practical distribution there is, first, the scheme of electrical division over the area to be supplied. The determination of this calls for the highest abilities of the electrician, and within its limits he deals broadly with the whole question, cost, &c. Secondly, the engineering questions to be solved with reference to conduits, means of insulating mains, &c., for underground work. We say underground work, although a good deal of the pioneer electric lighting in this country has been effected by means of overhead conductors. This has especially been the case in the distribution from the Grosvenor Gallery station, Bond Street, London, where nearly thirty thousand lights have been maintained, within a radius of two miles, entirely by the aid of house-top circuits. But the facilities offered by the recent Electric Lighting Bill Amendment Act will doubtless lead to most future schemes of distribution being carried out underground.

In the following pages, therefore, we propose to consider—1. *The simple single circuit*, with one and more lamps, adapted for arc lighting; 2. A few representative installations of *multiple arc lighting*, and means for controlling the electric activity therein; 3. The two-wire or *multiple arc* system, with and without feeders; 4. *The three-wire system*; 5. Indicators of potential in the distant mains; 6. *Mains and feeders*, *accessories*, &c.

With regard to the conduction of the current from the machines to the points where the light is emitted, some of the arrangements employed for arc lighting by Messrs. Siemens Brothers and the Brush Electrical Engineering Company, and the other leading companies, may serve as examples.

The current generated in the machine is conducted through a leading wire to the lamp or lamps; it passes in the lamp (in the case of an arc light) from one carbon point to the other, thereby producing the electric light, and returns through another wire (the return wire) to the machine. These two wires are usually known as "leads" and "returns." Mr. Massey recommends the adoption of these terms by electrical engineers generally, it being understood that the "lead" is to be connected to the positive (+) terminal of the dynamo machine. He further recommends the general adoption of a uniform method in laying the leading and return wires, by placing all "leads" to the *left* hand (looking from the machine towards the lamp), and all "returns" to the right.

This complete circle is called the outer (or exterior portion of the) circuit, and when it is unbroken and continuous it is said to be *closed;* if in any one part an interruption of continuity occurs, it is said to be *open.*

Leading Wires are manufactured of strands of copper wire, and are either naked or coated (insulated). Naked wire may be used for the return wire, and it is only when used as a return wire that it should be allowed to touch the earth. In some cases naked wire may also be used to lead the current to the lamps, but in such cases it must invariably be insulated from the earth by being attached only to porcelain or other insulators attached to walls, poles, or trees. No other wire or mass of metal—save binding-wire—must touch such a conductor, otherwise there is danger of leading off the current back to the machine or to the earth before it reaches the lamps. Coated or insulated wires are covered throughout their length by an insulating substance, such as gutta-percha, or india-rubber and tape.

Where it is carried through rivers or lakes, or buried under ground, the coated leading wire receives a further protecting covering of iron wires against external injury.

The following are some of the more frequently employed leading wires (Siemens' system):—

Leading Wire, Fig. 126, consisting of 7 copper wires, insulated with tape and india-rubber to a diameter of about 0·34″ (=8·5$^{\mathrm{mm}}$). For a distance of not more than 450 yards between machine and lamp, and a total length not exceeding 900 yards of wire.

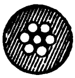


Fig. 126.—Section of Insulated Leading Wire.

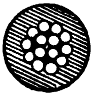


Fig. 127.—Section.

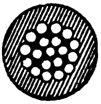


Fig. 128.—Section.

Plain Copper Strand of same diameter as in the above.

Leading Wire, Fig. 127, consisting of 14 copper wires, insulated with tape and india-rubber to a diameter of about 0·44″ (=11·2$^{\mathrm{mm}}$). For a distance of not more than 900 yards between machine and lamp, and a total length not exceeding 1,800 yards of wire.

Plain Copper Strand of same diameter as above.

Leading Wire, Fig. 128, consisting of 19 copper-wires insulated with tape and india-rubber to a diameter of about 0·48″ (=12·2$^{\mathrm{mm}}$). for a distance not exceeding 1,200 yards between machine and lamp, or a total length of not more than 2,400 yards.

BRUSH SYSTEM.

Machine	Approximate Equivalent in	
	Solid Wire.	Stranded Cable.
Nos. 1 & 2	No. 8 B.W.G.	7 strands of No. 16s B.W.G.
3	7 ,,	,, ,, ,,
4 (*a*)	8 ,,	,, ,, ,,
4 (*b*)	8 ,,	,, ,, ,,
4 (*d*)	3 ,,	7 strands of No. 13s B.W.G.
5 (*a*)	7 ,,	7 strands of No. 16s B.W.G.
5 (*b*)	8 ,,	,, ,, ,,
6	8 ,,	,, ,, ,,
7 (*a*)	8 ,,	,, ,, ,,
7 (*b*)		
8	8 ,,	7 strands of No. 16 B.W.G.

NOTE.—The resistance of one mile of 7 No. 16s is approximately 2·2 ohms, and every two miles of circuit with wire of this size may be considered equivalent to the insertion of an additional 2,000 c.p. lamp.

Cotton-covered wire of Nos. 12 or 14 B.W.G. is frequently used for conducting branches for groups of the incandescence lamps, and Nos. 16 and 18 may be employed for single lamps. For branches exterior to a building it is advisable to use the same wires insulated with india-rubber and covered with a protecting layer of tape saturated with india-rubber.

Fig. 129.—Connecting Single-wire Conductors.

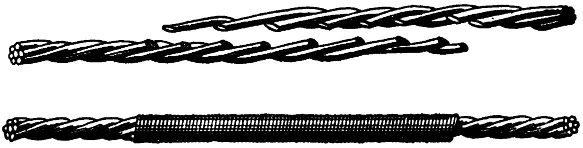


Fig. 130.—Twisted Wire Joint.

Figs. 129—131 represent some of the more useful wire and strand joints as used by the various companies. Each joint is intended to be soldered. Fig. 132 shows a connecting piece. Fig. 133 shows Clark's Telegraph wire joint. In leading the wires it is particularly to be observed that the "lead" and "return" do not come into contact. In most cases the wires should be kept apart to a regular distance. Six inches may be considered the minimum of safety, unless the electro-motive force of the machine be very low. The dryest route should always be selected in leading the wires. In permanent instalments the wires should be fastened down to floors or walls. In no case should metallic staples be used for this purpose. Leather tapes are the most suitable fasteners. They should be employed after the manner indicated in Figs. 134 and 135. In such cases small nails may be used if kept away from the wires.

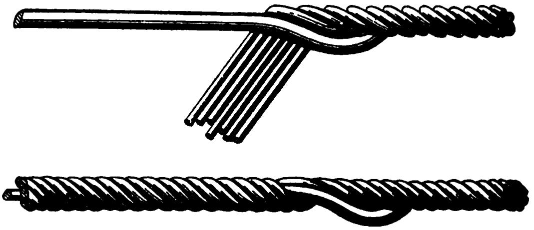


Fig. 131.—Connection between Stranded and Single Conductor.

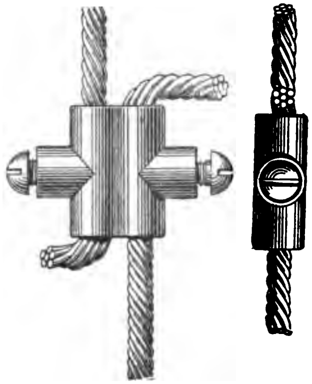


Fig. 132.—"Coupling-piece" for Leading Wires.

Abrasion of the wire coverings should be particularly avoided. They should therefore be placed in an undisturbed position, and as little slack as possible should be allowed.

The leading and return wires present a certain resistance to the current. The resistance is less as the wires are larger; it is, in fact, inversely proportional to the sectional area of the wire and directly as its length. The leading wires should always offer as small a resistance, compared with the source of light, as possible. The resistance is generally expressed in terms of the unit known as the ohm, which is approximately equal to the resistance offered by 210 feet of No. 16 B.W.G. of pure copper wire. In the usual form of electric lighting circuit, the resistances are those of the machine, leading wire, lamp (or lamps), and the return wire. When these are added together they are spoken of as the *total* resistance. Resistances are generally determined by means of a Wheatstone's Bridge and a case of resistance coils, by methods expressed in text-books of electricity.

Fig. 133.—Latimer Clark's "Britannia Joint."

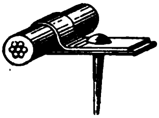


Fig. 134.—Tape Wall-fastening for Leading Cable.

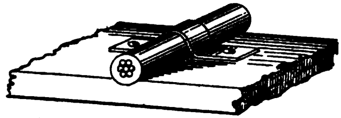
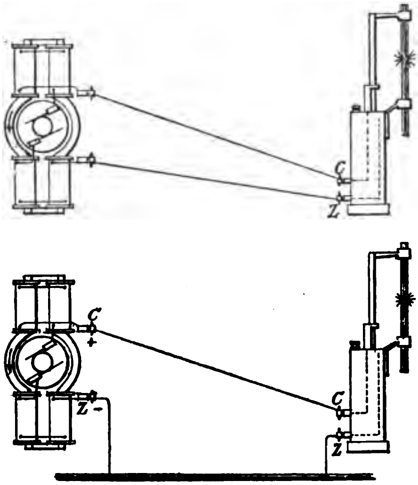


Fig. 135.—Floor-fastening.

General Circuit Arrangements.—This branch of the subject naturally divides itself into two great sections, namely, circuits for electric lighting by the arc system and those employed for the incandescence system. In order to elucidate the general arrangement employed with the arc system, we may select one kind of machine and lamp, namely, Siemens', and offer a few remarks concerning them.

In the case of a single machine and a single lamp, the connections between them are easily understood. The leading wire is connected to the positive terminal of the machine (generally marked C or +), and leads to the upper carbon of the lamp (generally marked C). When a "return" can be effected through gas or water pipes, or other continuous conductor of large size, the return wire may be dispensed with. Those two methods of arranging the connections are represented in the diagrams, Figs. 136 and 137 respectively. The return wire leads the current from Z of the lamp (the lower carbon) to Z of the machine, or



Figs. 136 and 137.—Circuits for Single Arc Lights.

its negative terminal (frequently marked —). When the machine is driven in the right direction, those connections will cause the current to flow from the upper carbon to the lower. If the upper carbon should not burn hollow, but pointed, the polarity of the machine may be assumed to have become reversed, causing the current to flow in the wrong direction through the lamp. In such case the wires at either machine or lamp should be attached to reverse terminals.

When several continuous-current machines are arranged to burn an equal number of arc lamps, it is found advantageous to add one more machine beyond the number of lamps to be fed, and use this machine to excite the electro-magnets of all the others. In such case terminal C of the exciting machine is connected with one extremity of the magnet coil of the first light-giving machine, and the other end of this wire with the commencing end of the electro-magnet of the second light-giving machine, and so on with the others until the extremity of the electro-magnet coil of the last machine is connected with Z terminal of the exciting machine.

The right-hand "brushes" or collectors of the light-giving machines, representing their positive poles, are to be connected to the terminals C of the respective lamps. The left-hand combs and the Z terminals of the lamps are thus connected to a common return wire. This arrangement is represented in the diagram, Fig. 138.

When the currents employed are alternating, and the Siemens' alternating current machine is used, the following connecting arrangements are necessary:—A small continuous-current machine, as shown in

Fig. 139, is used to excite the field-magnets of the alternating-current machine; its terminals are connected with the extremities of the field-magnet coils

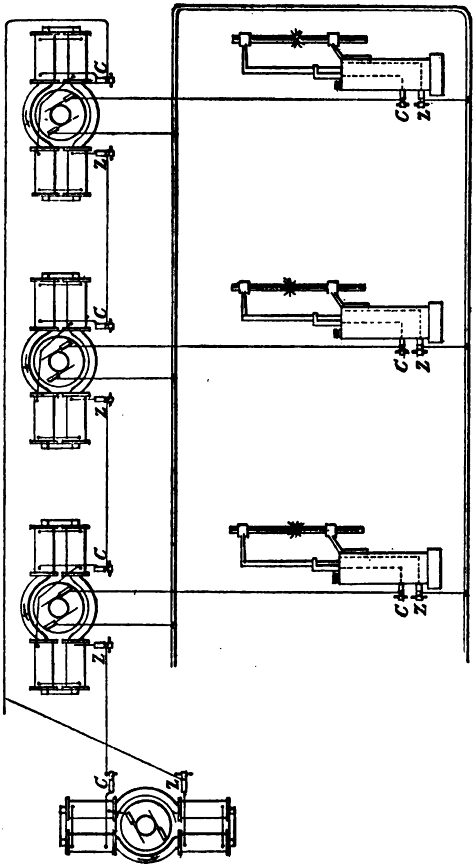


Fig. 138.—Arc Lighting Circuit Arrangements, with separate Exciter Machine.

of the large machine (lower terminals). The terminals on the contact rings of the alternating-current or large machine (upper terminals) consist of the black or "return" terminal, and the brass terminals equal in number to the circuits which the machine is constructed to work. The lamps are divided into as many groups as there are circuits, putting an equal number of lamps into each. The connections in each group of lamps are made as follows:—

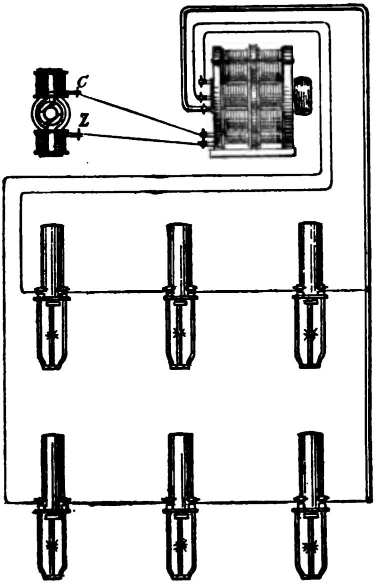


Fig. 139.—Circuit Arrangements for Siemens' Alternating Current Arc System.

One brass terminal on the contact rings of the machine is connected with each group. The connection leads from the brass terminal to first terminal of first lamp; from second terminal of first lamp to first terminal of second lamp, and so on until the second terminal of last lamp leads to the common return wire. The black terminal on the main machine is also connected to the common return wire.

When it is desired to open the circuit, whether in the case of continuous-current or alternating machines being used, the machine should, if possible, be stopped first, otherwise the "extra current" evolved by the sudden rupture is very apt to injure the insulation of the machine. It is better to open the circuit by drawing away the carbons in the lamp than to disconnect either of the leading wires.

Accessories, Resistances, etc.—Arrangements known as "bar commutators" are generally used in connecting several machines to several lamps, so that the lamps as well as the machines may become interchangeable among each other. They consist of a series of parallel metal bars placed above and insulated from a second series of metal parallel bars, in such a manner that the upper series run at right-angles to the lower series. The lower bars are furnished with terminals which receive the leading wires from the machines. The upper bars have also terminals which receive the leading wires from the lamps, resistances, &c.

The current being led from the machine arrives at the bar to which the wire is attached. Its progress is arrested at this point. When it is required to transmit the current to a particular lamp, a metal plug is inserted at the point where the bar connected with the lamp and the bar connected to the machine intersect. The current then flows through the plug from the lower to the upper bar, so completing the circuit. In cases where screws are used instead of plugs, care must be taken not to attempt to open the circuit at the bar commutator while the machine is in motion. If one of the screws be withdrawn under those conditions, a voltaic arc will be formed at the breach, and will begin to consume the upper bar and the plug. This arrangement is represented in Fig. 140.

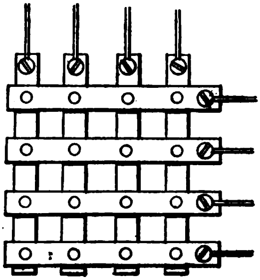


Fig. 140.—"Bar Commutator."

Resistance Controllers.—When an arc lamp or lamps are withdrawn from the circuit, the resistance of which should remain constant, an arrangement termed a "resistance frame" is inserted. This consists of a number of helices of iron wire so attached to connectors that one or more of the helices may be inserted into the circuit, according to the resistance required. Zig-zag lengths of iron tape are employed for the same purpose, and carbon rods have been much used by Messrs. Siemens. When the whole current is so passed through the resistance, much heat is developed, and in the case of employing helices of wire they should be exposed to the cooling influence of the air as much as possible. In some arrangements they are immersed in water. In Edison's system of lighting by incandescence, the resistances consist of copper wires wound around hexagonal or square frames, and freely exposed to the air. In this system, however, only a portion of the current—that shunted into the field-magnet is transmitted through the artificial resistance.

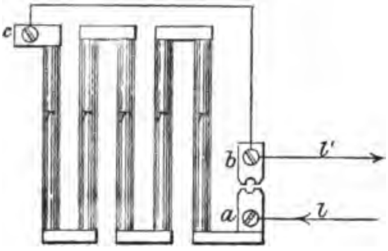


Fig. 141.—"Artificial Resistance."

The resistance arrangements employed in the Siemens systems of arc lighting usually consist of carbon-rods placed side by side upon a board, and connected with each other in such a manner as to create one continuous length of conductor. In Fig. 141, *r r* represent the carbon-rods; *a b c* are terminals. The leading wire into the circuit of which the resistance is to be placed is connected to the terminals *a* and *b*; *b* is further connected by a short thick wire to *c*. If the plug between *a* and *b* be inserted, the current will flow through *a* and *b*, and no resistance will be added to the circuit; but if the plug be removed, then *a* will be separated from *b*, and the current must traverse each one of the carbon-rods in succession. These resistance arrangements are constructed to suit the circumstances of each case.

In some cases it is found better to shunt a portion of the current through a resistance coil attached directly to the two terminals of the machine. In lighting by incandescence, the current from the armature is almost invariably controlled by weakening and strengthening the current exciting the field-magnets; for this purpose iron wire coils are generally used. The latter method is the more economical, because, if a lamp be abstracted from the main circuit (in the former case) and a resistance equivalent to it be inserted, the same energy is required to maintain the circuit as before, and the current is wasted in heating the resistance. In the latter case the current is generally small, and by inserting a resistance into the field-magnet circuit the amount of energy wasted in heat is practically inappreciable.

Siemens' Deviator.—This arrangement serves to substitute itself in an arc lamp circuit for a lamp which has accidentally become extinguished. It is a crude form of electric lamp, and indicates by the light it suddenly sends forth when beginning to act that the circuit to which it belongs has been severed or the lamps extinguished.

It is arranged according to the method represented in Fig. 142. E is an electro-magnet. It is wound with thick wire. One extremity of its coil is connected to the metal frame F, and the other to the terminal M. A is an armature sliding between guides, and bearing the upper carbon-rod C, and pushed by the spring S, through the rod R, away from E. F, and through it R, A, and C, are in contact with terminal L. The lower carbon-rod, C^1, is connected with terminal L M. The machine is connected to terminals M and L M; the lamp to L and L M. When the current passes through the lamp its course is as follows:—C terminal of machine, terminal M, E, F, terminal L, lamp-terminal L M, Z terminal of machine. Thus the circuit is closed. In its passage through E the current makes E magnetic, attracts A, and separates C and C_1; thus, when the current passes in the proper circuit the deviator does not burn.

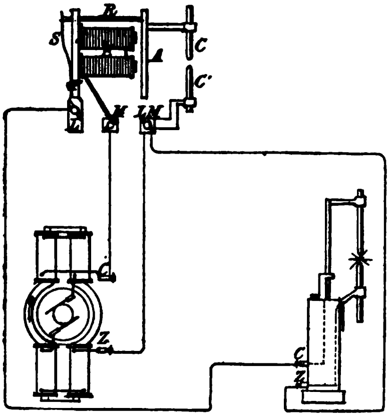


Fig. 142.—Arrangement of Siemens' "Deviator."

Circuits at the British Museum.—The Reading-room is illuminated by four inverted pendulum lamps, each lamp being fed by a separate dynamo-electric machine of the type D_2. In the corridors, the offices, staircases, and the engine-room, sixteen differential lamps are fixed, also forty-seven Swan incandescent lamps. The differential lamps are fed by an alternating current machine of the type W^2. Another machine of the same kind and size feeds the incandescent lamps. The four lamps of the continuous current circuits are directly connected to the machines, one common return wire serving for all four. The differential lamp circuits are arranged as follows:—In one circuit eight lamps are placed, and one artificial resistance. In the other also eight lamps are placed, but as these lamps are not always all burning, three artificial resistances are provided. By means of commutators, either one, two, or three resistances can be put into circuit, one resistance being commonly used for every two lamps withdrawn from work.

The diagram (Fig. 143) shows the circuits of this installation, with the exception of the incandescent lamp circuits, which have been added only recently. E shows the separate exciter, W the alternating-current machine, D D the continuous-current machines, R R R the resistances, L L L the lamps, and S S S S the commutators. The continuous-current lamps are approximately of 3,000-candle power each, suspended at a height of about 30 feet above the floor. The alternating-current or differential lamps are of 300-candle power, fixed at 15 feet above the floor. The forty Swan lamps are of 16-candle power each. The whole of the machines are driven by two 8 H.P. (nominal) semi-portable steam engines.

Circuit Arrangements at the Royal Albert Dock, London.—The area illuminated is about 9,000 feet long and 1,500 feet wide. The lighting is done by 27 inverted pendulum lamps, each one fed by a separate D^2 dynamo (Siemens') machine. The machines are distributed in four stations of seven, seven, seven, and six light-giving machines respectively. In each station an additional machine is used to excite the

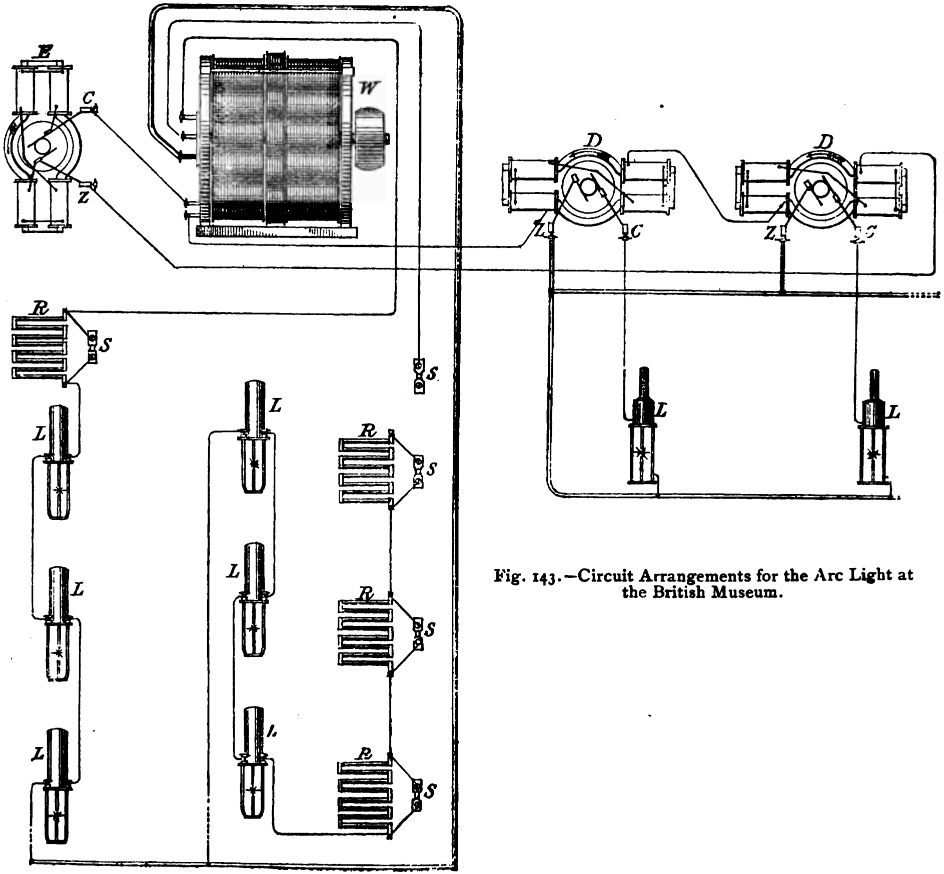


Fig. 143.—Circuit Arrangements for the Arc Light at the British Museum.

electro-magnets of the light-giving machines. The C terminals of the light-giving machines are connected to the lower bars of a commutator, the upper bars of which are connected through deviators (previously illustrated) to the lamps. All the Z terminals and lower carbons of deviators and lamps are connected to the common return wire. An electro-dynamometer is joined with the commutator, so as to allow of the measuring of the current in any one lamp-circuit. In the diagram (Fig. 144) E shows the exciter, D D D are the light-giving machines, S is the commutator, F the dynamometer, G G G the deviators, and L L L the lamps. The lamps are suspended from lattice iron poles at a height of 80 feet above the ground. Each machine station is provided with a 20 H.P. (nominal) steam engine. Besides these arrangements the dock-sheds have lately been fitted with alternating-current lamps of 300-candle power, which are adapted to extended circuit wires, so that any one lamp may be shifted to any particular part of the sheds.

Circuit Arrangements for Incandescent Lighting.—The method practically adopted for the feeding of incandescent lamps is almost invariably that known as multiple arc or connection in parallel circuit. According to this method, in its simplest development, two wires are led from the electric source; they are kept apart. The incandescent lamps are then connected so as to bridge across from one wire to the other. In Edison's system only one lamp is so placed to form one particular bridge; the arrangement thus consists of a large number of single lamps acting as bridges from one electrical main to the other. It is found that when the Edison lamp offers a resistance of 140 ohms when hot, an electromotive force from the machine, or, in other words, a difference of potential between the electrical mains of 110 volts, suffices to maintain the lamps when thus made to bridge the mains singly.

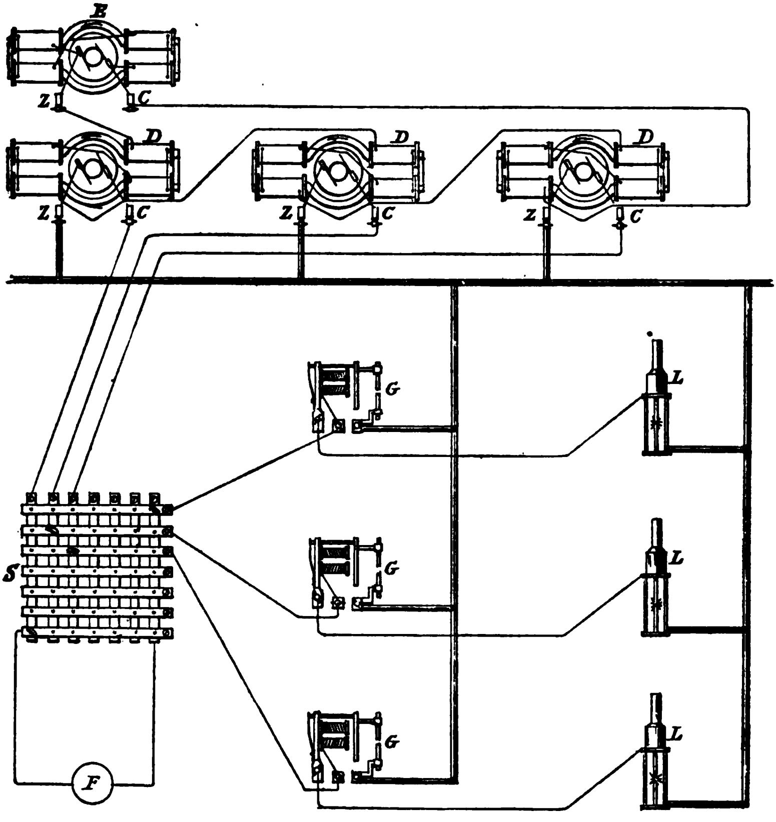


Fig. 144.—Circuit Arrangements at the Royal Albert Docks.

But when the lamp presents a much smaller resistance, or (using the same lamp) when the machine develops a much larger electro-motive force, it is found more economical to arrange the lamps in series of two or more, instead of singly, to bridge across the mains. This is frequently done with the Swan lamps and the Siemens machines. The number of lamps to be attached in series depends obviously upon the difference of potential between the mains, and upon the resistance of the lamps.

Fall of Potential.—When two long wires are led as mains from a machine, and the lamps simply bridged across, regardless of distance from the machine, it is found that the lamps nearest to the machine are brighter than those farthest from the machine. Hence, it will be found that the lamps at the extremities of two long mains would receive very little of the current, whereas those near the machine would be served with too much current. This difficulty is met by not attaching the machine to the two extremities of the mains as described, but more generally to their central portion, so that the current is more evenly distributed throughout the lamps, and branches are also frequently taken from the machine, so as to lead a due proportion of the current to parts of the mains which would otherwise not receive a due proportion.

This difficulty is analogous to that which would be encountered were we to lead a long gas-pipe carrying a moderate quantity of gas, and to fix upon it at intervals a large number of burners. Those burners nearest to the supply end would consume or be supplied with too much gas, while those at the farthest end would not be supplied with the required quantity. If, however, we were to arrange the burners in groups, upon branches from the main, the difficulty would not be so great to maintain each burner.

In the same manner, a given number of incandescent lamps can be more impartially maintained by arranging them in groups (or series of two or more) between the mains, when sufficient electromotive force is developed for that purpose. In Edison's system, where one lamp only is allowed to bridge across the mains, "feeders," or auxiliary leading wires, are so distributed that no portion of the parallel circuit can be supplied with more of the current than any other portion. It would appear that, although this method allows of several lamps being lighted or extinguished without sensibly disturbing the brightness of the others, the increased cost of laying leading wires for purposes of equal distribution would be greater than that of feeding the lamps in series of two or more, and so dispensing in a great degree with supplementary mains.

The "safety fusible plugs" employed in the Edison and Swan systems usually consist of a short length of lead wire. Their function is to melt and so sever the branch of the circuit in which they are placed, should an unduly strong current, by any accident, be transmitted into that branch. See "Fuses," p. 328.

The Three-Wire System.

Dr. J. Hopkinson, F.R.S., introduced this system in 1882. It has been very largely used in London, many of the thoroughfares in the West End having been served on the system. It is specially adapted for "low-tension" working over great distances.

It presents the advantages of carrying direct from the generating station a high potential, which may not be carried beyond the mains themselves. Hence, the houses are served at a lower potential than that of the mains. At the same time, since it is admissible to carry a high potential, the mains may be made of smaller cross section than usual in direct systems (*i.e.* systems in which transformers are not used), thus effecting a considerable saving in the cost of copper conductors. In order to combine the advantages of comparatively high potential in the feeding conductors with lower potential in the houses in which the electricity is used, Dr. Hopkinson conceived the use of *three conductors in combination with two dynamo machines coupled in series.* This is shown diagrammatically in Fig. 145, where A B represents the two dynamos, C D and E F represent the extreme conductors, which are called the positive and negative conductors, and G H represents the intermediate conductor. The positive pole of the dynamo machine A is conducted to the conductor C D, and its negative

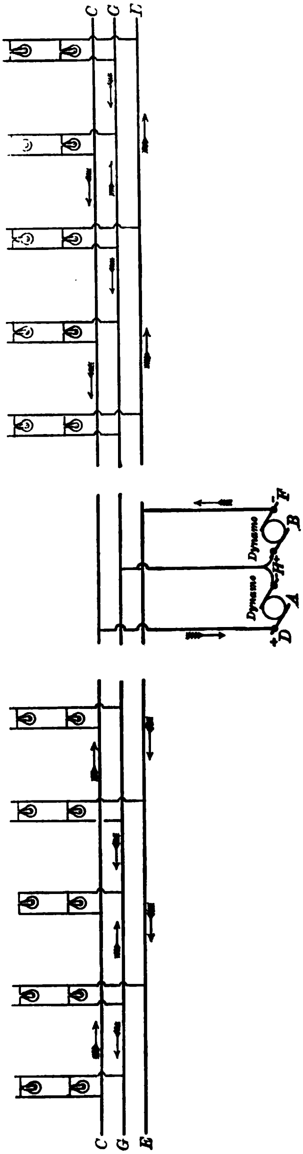


Fig. 145.—The Three-Wire System.

pole to the conductor G H. On the other hand, the positive pole of the dynamo machine B is connected to the conductor G H, and its negative pole to the conductor E F.

The houses to be supplied are divided into two approximately equal parts, preferably the houses being taken alternately. The houses of one part are supplied between the conductor C D and the conductor G H, and those of the other part between the conductor G H and the conductor E F.

The intermediate conductor G H may be of much smaller dimensions than either of the other two, as it has only to carry the *difference* of current consumed by the two divisions of consumers, that is, those connected with the conductor C D, and those connected with the conductor E F. It need not be insulated, and, indeed, it may be replaced by the iron or other metallic covering often used to protect the copper conductors. In cases where the two divisions of consumers may be safely assumed to have a very approximately equal consumption at all times, the intermediate conductor G H may be replaced in part by the earth, and the negative pole of the dynamo machine A, and the positive pole of the dynamo machine B be connected together and to the earth.

It is obvious that the system may be extended so that in a large station several dynamos may be connected in series, and dividing the consumers into as many groups there will then be two large conductors connected to the extreme poles of the dynamos and a number of smaller intermediate conductors, one less than the number of machines, each connected to the junction of two machines of the series.

Indicators of Potential in the Distant Mains.

When electric energy is delivered by means of a pair of conductors to a distance from the station where the dynamos are kept, there is a fall or loss of potential due to the resistance of the conductors, *greater as the current is greater*, and as in electric lighting it is imperative that the potential shall remain approximately constant (in the best systems it varies less than five per cent. from light to full load), the potential at the supply end should be regulated to meet the call for current.

Pilot wires.—It is not enough that the potential, or fall of potential, at the supply end be known. It is far more important to be informed as to the actual potential of the mains at the various points of consumption. For low tension constant current systems this is usually accomplished by the use of "pilot wires;" that is, fine wires taken direct from the mains to the generating station, from different points. These wires indicate upon a volt-meter the potentials at the far end. The old practice was to run the pilot wire parallel to the feeder, and to attach its far extremity to the point where the feeder strikes the main. It has been found, however, that this, although affording an approximate indication of the loss of potential, is not necessarily accurate within narrow limits—that the lamps might become too bright or too dull when situated at some distance from the feeder. The present practice is to run the pilot wires to the various seats of supply, so as to obtain instant warning of the actual fall or rise of potential very near to the lamps. In such case the wires are usually run parallel with the mains, or shorter direct routes, where the mains may be struck, are chosen. In the construction of feeding cables these pilot wires are generally *separately insulated* and stranded along with the naked cable, prior to the putting on of the main insulation. This is very convenient, and does not preclude the pilot wire being continued alone beyond the point where the feeder intersects the main.

Hopkinson's Indicator.—In circuits of the high tension system it is not essential that an independent and direct indication of the potential at the extreme end of the mains be taken by means of pilot wires. Several instruments are in use by which it may approximately be determined at the generating station. Dr. Hopkinson's Indicator belongs to this class. When the electricity is to be used at a distance from the dynamo, and conductors of a sensible resistance are employed, it is requisite to maintain constant the difference of potential at the end of such conductors and not at the dynamo itself. If E be the difference of potential of the poles of the dynamo; R the resistance of the conductors from the dynamo to the place where the electricity is to be used; and C the current; it is required to maintain not E constant, but E — R C, which is equal to the difference of potential of the two conductors at their far extremity. The instrument for attaining this is shown diagrammatically in Fig. 146, where A is the dynamo, B are the lamps, all placed near each other, connecting the conductors, but all remote from A. The apparatus is wound with a coil of thin wire making many convolutions. This coil is connected to the poles of the dynamo at E and F and is therefore a shunt to the circuit; it is in fact a potentiometer coil. The apparatus is also wound with a thick coil through which a portion or the whole current may pass from G to H; the direction of the current in the thick coil being opposite to that in the thin coil, as indicated by arrows. The thin wire is of German silver, to secure approximately constant resistance.

This differentially wound volt-meter may be used as a potentiometer simply, on the principle of any of the forms in use, or it may be used in the form of a relay, for the purpose of ringing a bell, or otherwise giving warning of a change in the potential and current. One form of relay for this purpose is suggested by Dr. Hopkinson, and is shown in Fig. 147. A and B are the coils of thick wire wound upon the limbs of an electro-magnet, and C D the coils of thin wire, both wound on the same core, the preponderating effect of the thin wire being opposed by the spring E attached to the moveable

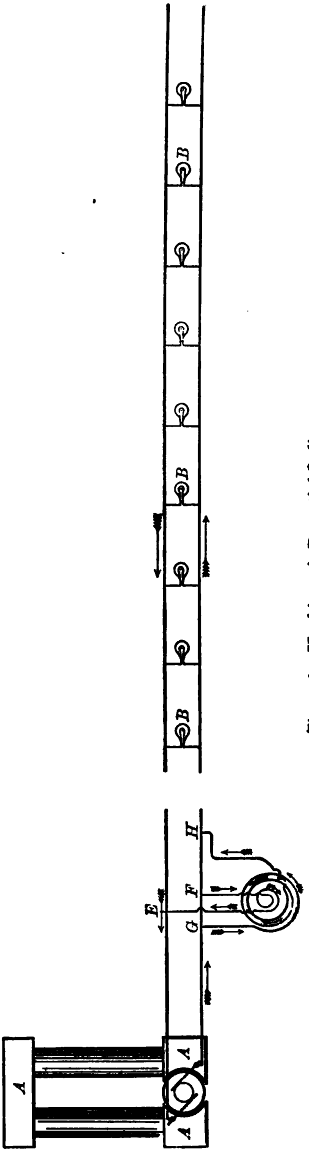


Fig. 146.—Hopkinson's Potential Indicator.

armature G, carrying the contact piece F, which makes contact with H or I according as E – R C is too great or too small, and so closes the circuit of one or other

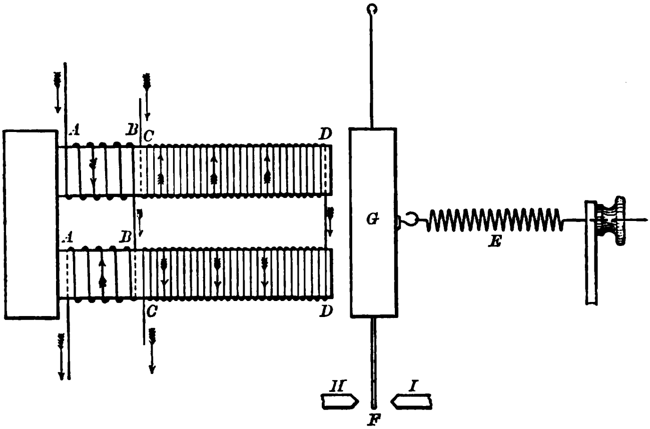


Fig. 147.—Hopkinson's Indicator.

of two electric bells, or of other suitable indicating apparatus.

Mains and Feeders.

According to the practice of the larger electric lighting schemes in use in America and Europe, *mains* are generally considered as distinct from *feeders*.

A main may be defined as a trunk line, from which consumers draw their supply direct, and it may be supplied with electricity at more than one point. When more than one main exists in the same district, they may or may not be connected together, according to the requirements of the consumption. Mains are generally arranged in a *network*, to cover a district, taking in all the points of probable consumption. The planning of such a network opens up questions of the deepest interest to the electrician. His aim will be to so connect its separate parts as to economise energy, and to maintain them at a proper potential against all probable demands. If the mains are worked at a moderate tension (low tension system) different points (where the demand for energy is greatest) will be in direct communication with the central station by means of thin "pilot" or potential wires. Such a system enables the attendant to ascertain at a glance the variations of potential at the points of consumption. The variations cannot easily be determined at the dynamo, because the potential at the station and at the remote end of a main are not necessarily coincident unless mains of extravagant size be used.

It has been said that a constant pressure must be maintained upon mains. In systems of incandescent lighting this is imperative. The reason is not far to seek. If a glow lamp takes an electric pressure of 100 volts to incandesce it to its standard (8, 10, 16, 20 candle-power as the case may be) a fall of ten or twenty volts would make a very great difference in the amount of light, frequently 50 per cent. If, on the other hand, the voltage should rise to a similar amount, the lamp would become very much brighter, and would probably be "burnt out" in a short time. It is therefore important to guard against making the lamps appear "like red-hot hair-pins" on the one hand, and the destruction of the filaments upon the other.

Material, etc., of Mains.—Mains being simply copper conductors of considerable capacity, different authorities advocate distinct shapes or particular forms of construction. The most usual form is that of the stranded conductor, having many wires, acting as one, shown in section in Fig. 128, p. 301. These cables are generally heavily insulated in gutta-percha, hemp, jute, vulcanised rubber, &c., and are frequently further "armoured" by a sheathing of twisted iron wires. Or the cable is, after being insulated, covered with lead. The object of so much expenditure upon insulation, &c., is simply to cheapen the cost of constructing trenches or conduits, and of providing means for high insulation therein. But the system in use in Paris upon a large scale has proved that naked cables may be used with every advantage. In this system the cables (of silicum bronze) are carried in conduits of concrete, beneath the kerb, upon insulators of porcelain placed about every six feet. The insulation of these mains is said to be very high. The same system has been extended to London, where a large proportion of the work has been done upon the three-wire system, the conductors being in many cases of "strap" copper, carried upon insulators in suitable conduits.

There is little reason to doubt that the mains of the future will be chiefly of naked copper or bronze, and preferably of the "strap" form, especially for high-tension work.

Several patents have been taken out for particular methods of constructing and insulating the mains. One of the most interesting of these is the invention of Ferranti (No. 2,315, 1888), who proposes to employ a twin main, the core of which is to convey the negative or positive current from the dynamo. The core is heavily insulated from the exterior metallic sheathing, which forms the "return." The main is composed, first, of a copper tube of small diameter, surrounded by a considerable thickness of insulating material, the whole being enclosed in a copper or other metallic tube, about three inches in diameter. It is to be particularly observed that the "return" is intended to be put in connection with the earth, and that only the core is to be maintained in a carefully insulated condition. This is known as the "concentric" method of construction. This main is constructed in lengths, and suitably jointed together. The Ferranti system employs high tension alternating currents, and these mains are intended to be used for conveying electricity to Central London from the large generating station at Deptford, where the Ferranti system is exclusively employed. It is questionable whether concentric mains will, except where a large supply is required, take the place of insulated cables.

Concentric mains on the same principle, but with both conductors insulated, are being largely used, especially on the Continent. The concentric method minimises the loss of energy usually arising from self-induction, especially when alternating currents of high tension are in question.

Junction Boxes—Distribution Boxes.—At certain points along the course of a main it is necessary to provide mains for connecting feeders, examining the mains, and for making connections for consumers' supply, in the form of wells or man-holes, easily accessible from without. These are known as junction boxes.

Feeders.—The chief distinction between mains and feeders lies in the fact that a main is a conductor that may be tapped at any point for consumers' supply, while a feeder is a conductor leading direct from the dynamo-machine or other source of electricity to the main, and is not tapped on the way. The cross-section of feeders is generally much smaller than that of mains.

Electric Light Conduits.—It may be thought that the extensive experience of underground wiring acquired by the Postal Telegraph Department might possibly afford a safe guide to engineers in the work of laying electric light feeders or mains. But such is not the case. The conditions are very different. The currents to be carried are enormously greater, tension is similarly higher, and there is also the question of frequent tapping along the course of the main. The electric light conduit can hardly be said to have emerged from the experimental stage, and every likely form is under test. Conditions, too, vary greatly. The proximity of gas, water, and other mains have a certain influence, and the nature of the roadway, with the traffic carried, also bears strongly upon the success or failure of a particular class of conduits. Mr. John B. Verity read a paper before the Institute of Electrical Engineers, on April 11th, 1889,* in which an extensive experience of electrical conduits, both at home and abroad, finds practical expression.

The Fuse and the Cut-out.—In the wiring of buildings for the electric light certain precautions are usually taken against the risk of fire. There may be said to be a possibility of the wires leading from the mains becoming hot enough to ignite dry woodwork under certain conditions, which, however, seldom or never occur in practice. But to satisfy the stringent

---

* See *The Electrician*, April 26, 1889.

rules issued by the fire insurance companies, it is usual to insert in the circuit certain portions of conductor that will easily *fuse* upon the wires becoming hot, and so *cutting out* the faulty circuit from the main supply. Such an accident might, for example, take place if the two house wires came into conductive contact within the building. This *short circuit* from the fault to the mains would then in all probability become very hot, or an electric arc, capable of setting fire to inflammable substances, might ensue at the fault if the contact were only partial.

Hence, to protect a moderate length of such house-circuit, a pair of fuses are placed at its junction with the mains. This is the correct position for the first fuses, but it is not always convenient to place them in that position. If a considerable number of lamps are to be run by the circuit, so that it takes the form of a pair of sub-mains with branches, fuses should be fixed at the root of each branch. But *fuses should be used sparingly*, as too free a use of them will introduce dangers greater than those they are supposed to avert.

A fuse is a short length of tin or lead wire, or it may be of tinfoil. Tin wire has been found the most suitable substance, because it does not easily oxidise, and melts without "firing."

Mr. A. C. Cockburn read a paper on "Safety Fuses for Electric Light Circuits" at the Institute of Electrical Engineers on December 8, 1887,* in which he describes various instructive experiments bearing upon this question. The alloy he recommends is composed of tin with the addition of 5 per cent. of phosphorus. This is stated to fuse at a temperature of 235° C. Various alloys are used; but for general

---

* "Journal" of the Institute.

purposes in this country electrical engineers are agreed that tin wire or foil answers the purpose sufficiently well. Numerous devices have been invented for affixing the fuse to the leading wire. "Plugs" of fusible alloy are frequently used to close the circuit between the two ends of the wire; the fusing of the "plug" and the dropping out of its substance breaking the circuit. As the fuses have to bear currents of various powers without the chance of rupture, they are constructed in various sizes, as capable of feeding 5, 10, 20, 100 lamps, &c., without melting. The fuses are thus generally marked with the current they are intended to safely carry. In the selection of fuses it is important to observe that when the fuse melts its substance *drops* by gravity away from the wires, so completely severing the circuit. Sir William Thomson and others have introduced fuses in which a spring is employed to rupture the circuit upon the alloy becoming overheated.

Switches.—A great improvement has recently been effected in the switches used for opening and closing the main circuits by the introduction of Mr. Hedge's *double-pole switches.* This, if placed at the root of a main branch, can be used for disconnecting both wires simultaneously from the mains. Simple or single switches are made in immense variety. The chief requisite in a switch is, first, perfect contact, and, when opened, a sudden and complete severance of the circuit. This is usually effected by a spring, so that when the switch is once moved it opens suddenly of itself. "Switch-boards" and distribution boxes, as used for large installations and central depôts, scarcely come within the range of the present pages. Many of them are of wonderful ingenuity.

Electrical Measuring Instruments.

Siemens' Electro-Dynamometer.—This instrument (Fig. 148) is generally used for measuring the current from either continuous-current or alternating-current machines. It consists of a wooden frame placed on three levelling screws. On the lower (horizontal) part of the frame three terminals are arranged; to the upright part a fixed coil of two insulated copper wires is attached, and to the upper end of the frame a disc with a movable axis. The circumference of the disc

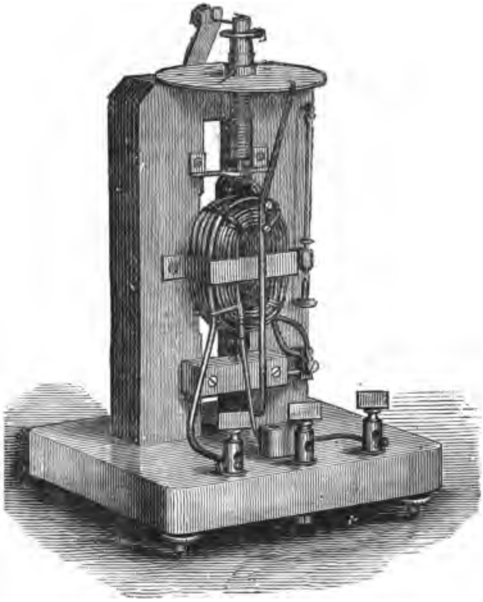


Fig. 148.—Siemens' Electro Dynamometer.

is divided into degrees. The two wires of the fixed copper coil are connected each with one end to a terminal and with the other end to a mercury cup. The two wires are of unequal thickness, the stout one being connected to terminal 3 and the mercury cup and the thin one to terminal 2 and the cup. From the axis of the disc hangs on a fine spiral spring a movable loop of stout copper wire, which dips with one end into the mercury cup and with the other into a second mercury cup below the first one. This second mercury cup is connected to the central terminal.

The loop bears an index arm reaching up to the circumference of the disc. The movable axis from which the loop is suspended bears a pointer, which is fixed to it by a collar and a small screw. The top of the axis has a screw head. A plumb-bob attached to the frame serves to place the instrument in a perpendicular position. A small horizontal axis with screw-head in its outer end, and resting on the larger movable axis with its inner end, holds the suspension of the copper loop, and by turning it one way or another the copper loop is lifted so as to move freely, or let down so as to rest immovably.

For use, place the instrument on a firm basis, put it into a position that the plumb-bob will hang perpendicularly, lift the loop to move freely, and see whether the index arm on the copper loop and the pointer from the axis both point to zero on the disc. Should they not do so, turn the vertical axis until the index arm does, and then loosen the screw on the collar of the pointer and turn the pointer until it also rests on zero, then screw the pointer fast again. The wires of the circuit, the current of which is to be measured, are connected to terminals 1 and 3, if a strong current is to be measured, or to terminals 1 and 2, if the current is weaker.

The current then, in the first case, enters at terminal 3, passes through the stout wire of the fixed coil into the upper mercury cup, through the movable copper loop into the lower mercury cup, and leaves at terminal 1.

While passing, the current makes the loop turn from its position of rest, and its index arm therefore leaves the zero on the disc. The movable axis must then be turned until the index arm has returned to zero, and the angle through which the axis has been turned is shown by the pointer on the disc.

If several currents are measured by this instrument they bear the same proportion to each other as the square roots of the respective angles observed.

A table at the back of the instrument gives the constants to be used for calculating from the angle the current in ampères. These constants only hold good, however, for the particular spiral spring which was in the instrument when the constants were determined. A later form of the instrument, so arranged that it can be used aboard ship, and that the reading can be taken direct from the dial, was described by Mr. Alexander Siemens at the Society of Telegraph Engineers, December 1, 1887.

Siemens' Watt-Meter.—This instrument is intended to measure at one operation the activity in a circuit. It somewhat resembles the same maker's dynamometer, which is more especially intended for the measurement of alternating currents. Here we deal direct with both the current and the potential, and obtain at one reading the watt-energy in the circuit. The instrument consists of a coil of fine wire of rectangular shape, and of a single rectangle of very thick wire, capable of moving over the fine wire coil. In these respects the instrument is very similar to the dynamometer already described except that the wire in the coil is much finer, and acts as a potentiometer, or volt meter, and the single turn much thicker. The movable coil is suspended by a torsion spring in the same way. The connections with the circuit are so arranged that the whole of the current passes through the thick coil. The fine coil is connected as a loop or by-pass, and, of course, only takes a proportion of the current—this current is always proportional to the difference of potential between the extremities of the mains being measured. When the currents pass there is an attraction between the coils tending to pull them into the same plane. The torsion spring is now brought into play, and is rotated by hand until the coils are brought back to the position at right angles to each other, as in the case of the dynamometer. A table accompanies the instrument, showing at once for every given degree of torsion so imposed the electrical activity in watts.

Ayrton and Perry's Ammeter.—This instrument depends upon the principle that a fragment of iron, if placed in a magnetic field, will, if free to move, place itself in the strongest part of that field. A peculiar form of spiral spring is also used in the ammeter (or ampère meter) so adapted as to rotate in proportion to the pull exerted upon it. Within a vertical tube of soft iron is placed the small piece of iron of cylindrical shape, suspended by the spiral spring already mentioned. The upper end of this spring, which is free to rotate, carries a pointer moving over a dial, graduated. The instrument is rendered active by a solenoid (of insulated wire) surrounding the iron tube, and a certain distance beyond it, downwards. The iron piece being suspended just at the base of the iron tube is pulled downwards, when the current is passed, into the space below the tube, and in this motion exerts an effect upon the spiral spring, so rotating the pointer. Since the pull is proportional directly to the current passing, and the rotation of the pointer is in unison, the instrument presents the great advantage of showing direct the current in ampères upon an equally graduated scale. A very complete protection from outside magnetic or electrical influences is given to the ammeter by a sheathing of iron plate.

Voltmeters.—The instruments spoken of above are more especially adapted to the measurement of current. To determine the electrical pressure or potential a rather different class of instrument has come into use. These are known as *voltmeters* (as indicating how many volts pressure), potential galvanometers or potentiometers. The general principle of the voltmeter is the same as that of the current meter. The chief difference lies in the high resistance of the voltmeter coil or conductor, as compared with the low resistance of the current meters. On the other hand, a current-measuring instrument will measure the volts, provided it does not admit of an appreciable flow of electricity. So that many current-meters are easily converted into voltmeters by exchanging the low-resistance coil for one of very high resistance.

Sir William Thomson has devised many beautiful instruments for this purpose, and his gravity voltmeter is well-known to working electricians. It consists essentially of a conical solenoid having a very high resistance (200 ohms, a coil of fine wire in the shape of a cone). A short stumpy piece of soft iron is suspended in the interior of this coil, balanced from the short end of a light "steelyard" of aluminum, moving over a graduated scale. When the current passes it produces a magnetic field in the coil, which (on account of the cone shape) is stronger at the top than at the bottom. The iron bob is thus attracted further upwards into the coil, carrying the steelyard with it. The long end of the steelyard then shows at once the potential in volts. An additional resistance of platinoid wire, of 2,000 ohms, is also included in the circuit. No spring is used in the instrument, the counterforce being gravity, which is constant for any position of the steelyard. This voltmeter is adapted for constant currents.

Cardew's Voltmeter.—A great deal of practical work is being done with the excellent voltmeter devised by Captain Cardew. This voltmeter does not depend upon electro-magnetic action. It is extremely simple, depending merely as it does upon the elongation or sagging of a stretched platinoid or platinum wire when currents are passed through it. The instrument consists of the stretched wire, one end of which is rigidly attached to the framework, while the other extremity is kept tight by a spring. This end of the wire is attached by a multiplying motion to an indicator moving over a dial, graduated in volts. The finger shows the volts at once. The wire is stretched within a long tube, the material of which, it has been found, must have the same co-efficient of expansion as that of the wire itself. The tube is, therefore, made partially of iron and partially of brass. When connections from the extremities of the wire (usually through a resistance coil) are made to the dynamo terminals or mains, the pressure in which it is desired to ascertain, the finger is immediately deflected; but it does not take up a steady position immediately. This is owing to the gradual heating of the wire, and not until the increments of heat produced by the current are balanced by the heat lost by the wire by radiation, convection, &c., does the true potential appear upon the dial. The instrument is made to suit various voltages, and is considered the most reliable form of voltmeter, especially for electrical pressures under 1,000 volts. In most cases where the Cardew voltmeter is in use at central stations, it is kept permanently connected with the mains, and indicates within narrow limits the variations of potential.

Messrs. Ayrton and Perry* have devised certain improvements upon the well-known Cardew instrument. In their improved voltmeter they have utilised the Cardew principle of the sagging wire, but have both modified the disposition of the wire and wedded thereto their ingenious torsion spring, as described in connection with their ammeter (p. 334).† The platinoid wire in Messrs. Ayrton and Perry's instrument is rigidly attached at both extremities, and the indications are taken from its central portion, the indicating torsion-spring, carrying a pointer moving over a dial, being attached thereto. The instrument is said

---

* Paper read at the Institute of Electrical Engineers, January, 1888.

† Proceedings of the Royal Society, No. 230, p. 311, 1884.

to be especially accurate for the measurement of low tensions.

Dr. Fleming and Mr. Gimmingham have brought out a useful form of portable voltmeter, which is recognised as the standard instrument of the Edison-Swan Company.

CHAPTER XI.

MEASUREMENT OF THE ARC LIGHT.

PHOTOMETRIC measurements, as applied to the light produced by electricity between two carbons points, are not so easily obtained accurately as may be supposed. The value is usually given in terms of comparison with the standard sperm candle, burning, as nearly as possible, 120 grains per hour.

London gas, with a burner consuming about 5 cubic feet of gas per hour, gives an average illuminating power of 15 standard candles, Liverpool gas 16; and the gas of other towns varies in quality so greatly that gaslight should never be employed as a standard of measurement unless its actual value has been determined. In France the measurement is usually made by comparing with the light of a Carcel lamp, burning 648 grains of pure oil per hour. An ordinary gas-jet, burning 4½ cubic feet per hour, is equal to 1$\frac{1}{10}$th of a Carcel light as above. A burner consuming 7 feet per hour is equal to 1·72 Carcel lights—taking 16-candle gas.

The intensity of the beam of electric light varies considerably according to the relative positions of the carbons. Thus, if a carbon having a square section be placed so that its axis corresponds with the line of one of the angles of the other carbon, the beams of light in different directions will vary as much as the ratio of 38 to 287, and even when the axis of one carbon lies properly in a prolongation of the axis of the other, the beam will vary with the angle formed by the beam with the axis of the carbons. Thus it is stated that the beam at right-angles to the axis has measured 970 candles only, whilst that measured at 45° with the axis of the carbons has been 2,000 candles. The light should, therefore, always be measured on a beam at right-angles to the axis of the carbons.

Rumford's Photometer is one of those often used, and its simplicity recommends it to the practical electrician. It consists simply of a calico or other screen, in front of which, and about a foot from it, is placed, vertically, an opaque rod of any material, such as blackened wood. The lights to be compared—for example, a candle and a gas-jet, are placed at different distances from the rod, and the gas-jet is moved until the shadow it casts from the rod upon the screen is equal in intensity to that produced by the candle, which will, of course, be much nearer to the rod. The intensity of light diminishes as the square of the distance increases, or in other words, *the intensity of the light is inversely proportional to the square of the distance.* Since the intensity of a light at twice the distance is one-fourth, and at three times the distance one-ninth, it is obvious that if two sources of light, of which one is placed at a certain distance from the surface while the other is placed at a distance twice or three times as great, produce equal degrees of illumination, the illuminating power of the more distant light must be four or nine times as great compared with the illuminating power of the light which is nearer to the surface. From this it is clear that when two sources of light produce equal intensities of shadow upon two surfaces at unequal distances, their illuminating powers are in the ratio of the square of their distances from the illuminated surfaces.

Unfortunately, a difficulty is introduced in such work by the redness of a candle light and the intense violet rays given off by the electric arc light. For electric arc light measurements it is found better to use Bunsen's photometer, which enables the intensities to be compared with greater accuracy than is possible by the use of the opaque rod and screen. The difficulty consists in the very different appearance presented by a shadow cast by the reddish candle, and that given from the brilliant electric light.

Bunsen's Photometer consists of a square wooden frame, over which is stretched a piece of white paper having a circular grease-spot in the centre. When lights are to be compared, a straight line is drawn upon a flat surface, the paper screen is placed vertically upon it with its centre on a level with the two lights, which are arranged upon either side of it. The stronger light is moved away upon the line until the grease-spot is not visible, and then, as before, by measuring the distances between the lights and the screen and comparing them, the power may be determined with considerable accuracy. A wax-spot is best made by dropping melted stearine upon the paper, removing it with a knife, and weakening the strength of the spot by passing blotting-paper on either side of it under a hot iron. If the spot be too strong, it will be difficult to arrive at a correct estimate of the values.

Equal advantages should be given to both lights.

For example, if the electric light be thrown upon the screen from a parabolic reflector, the candle-light should be also provided with a similar backing. If the electric light be diffused, the candle-light should also be diffused, and care is necessary to have the backgrounds and sides near to the lights equal in colour or reflective power. Care is also necessary that the experiment be made in an otherwise dark place.

In the experiments undertaken by the Committee of the Franklin Institute to determine the efficiency of the dynamo-electric machines placed in their hands, namely, the large and small Brush, the Wallace-Farmer, large and small, and one of Gramme's machines, care was taken, in order to make the measurements as accurate as possible, so to arrange the apparatus that no reflected or diffused light should fall on the photometer, and thus introduce an element of error.

The electric lamp was enclosed in a box open at the back for convenience of access, but closed with a non-reflecting and opaque screen during the experiments. Projecting from a hole in the front of the box was a wooden tube, 6 in. square inside and 8 ft. long, with its inner surface blackened to prevent reflection, thus allowing only a small beam of direct light to leave the box.

The beam of light passed into a similar wooden tube, placed at a proper distance from the first (about 30 ft.), and holding in its farther end the standard candle. This tube also held the dark box of a Bunsen photometer, mounted on a slide, so as to be easily adjusted at the proper distance between the two sources of light. A slit in the side of the tube enabled the observer to see the diaphragm and grease-spot. The outer end of the second tube was also covered by a non-reflecting opaque hood, and the room was, of course, darkened when photometric measurements were taken. The rigid exclusion of all reflected or diffused light is believed to be the only trustworthy method of obtaining true results, and will, no doubt, account in a great degree for the lower candle-power obtained in these experiments than that given by many previous experimenters.

The difficulties encountered in the measurement of the light, arising from the difference in colour, were at first thought to be considerable, but further practice and experience enabled the observer to overcome them to such an extent that the error arising from this cause is inconsiderable, being greatly less than that due to the fluctuations of the electric arc itself.

The Franklin Institute Committee considered what advantage would be gained by using a larger source of light than the standard candle, but after making several experiments with gas flames and the oxy-hydrogen light, they determined to use a standard candle only, making corrections for any variations in the rate of consumption of 120 grains per hour.

In determining the light-giving power of the current produced by the different machines, a continuous run of from 4 to 5 hours was made, and great care was taken to keep the axis of the two carbons of the lamp in the same line. To facilitate observations, a lens was placed in the side of the electric lamp box, in line with the carbon points. The axis of the lens was at right-angles to the beam of light going to the photometer, and an image projected upon a screen, from the lens, enabled the observer to note the condition of the carbon points without distressing the eye. Photographic views of the carbon points were also taken at the moment of making the photometric observations, and care was observed that, at the moment of making the measurement, there was no fluctuation or moving from side to side of the electric arc.

The first of the following tables exhibits the results obtained by the Franklin Institute from their photometric measurements of the lights from the Brush machines, large and small; the Wallace-Farmer machines, large and small, and the small machine of Gramme, made by Breguet, and sent by him to the Philadelphia Exhibition. The second table gives some particulars of the experiments made at the South Foreland by Mr. (now Sir James) Douglass, the engineer to the Trinity Board, in 1876 and 1877.

The measurements of electric lights made by the Franklin Institute, and those by the Trinity House authorities, thus include particulars of the chief machines then in use.

It is but fair to the proprietors of the Gramme machine, as tested by the Trinity Board, to state that the type of apparatus tried was not the best in use, and that the Gramme has since been found in practical working to very nearly reach the candle-power per horse-power of the smaller Siemens machine.

According to Messrs. Sautter, Lemonnier and Co.'s experiments, made by them in Paris, they give for the Gramme machines:—

A type 2,400 }
C type 2,800 } Standard candles per H.P.
D type 3,125 }

TABLE SHOWING WEIGHT, POWER ABSORBED, LIGHT PRODUCED, ETC., BY DYNAMO-ELECTRIC MACHINES TESTED BY A COMMITTEE OF THE FRANKLIN INSTITUTE, 1877—8.

Name of Machine.	Weight.	Copper Wire in				Revolutions of Armature per minute.	Horse-Power.	* Light in Standard Candles.		Foot-lb. Power consumed per Candle.	Size of Carbons.	Length of Carbon consumed per hour.	
		Armature.		Field Magnets.				Total.	Per H.P.			+	-
	lb.	in.	lb.	in.	lb.							in.	in.
Large Brush .	475	·081	32	·134	100	1,340	3·26	1,230	377	87·4	$\frac{3}{8}\times\frac{3}{8}$	1·78	·34
Small Brush .	390	·063	24	·196	80	1,400	3·76	900	239	137·	$\frac{3}{8}\times\frac{3}{8}$	1·91	·58
Large Wallace.	600	·042	50	·114	125	800	—	823	—	—	—	—	—
Small Wallace.	350	·043	18¾	·098	41	1,000	3·89	440	113	292·	$\frac{1}{4}\times\frac{1}{4}$	2·45	·073
Small Gramme	366	·059	104	·108	104	800	1·84	705	383	85·	$\frac{1}{4}\times\frac{1}{4}$	3·15	·55

TABLE EXHIBITING DIMENSIONS, WEIGHT, LIGHT POWER, AND HORSE POWER ABSORBED IN THE MACHINES TESTED BY THE TRINITY BOARD, 1876—7.

Name of Machine.	Dimensions.			Weight.		Horse-Power Absorbed.	Revolutions per Minute.	* Light produced in Standard Candles.		Light per H.P. (condensed).	Light per H. P. (diffused).	Sizes of the Carbons.
	Lngth.	Brdth.	Hght.					Condensed.	Diffused.			
	in.	in.	in.	cwt.	lb.							
Holmes	59	52	62	51	35	3·2	400	1,523	1,523	476	476	$\frac{3}{8}\times\frac{3}{8}$
Alliance	52	54	58	36	49	3·6	400	1,953	1,953	543	543	$\frac{3}{8}\times\frac{3}{8}$
Gramme (No. 1) .	31	31	49	25	56	5·3	420	6,663	4,016	1,257	758	$\frac{1}{2}\times\frac{1}{2}$
„ (No. 2) .	31	31	49	—	—	5·11	420	6,663	4,016	1,257	758	$\frac{1}{2}\times\frac{1}{2}$
Siemens' (Large) .	45	29	14	11	74	9·8	480	14,818	8,932	1,512	911	$1\frac{1}{16}\times1\frac{1}{16}$
„ (Small) .	26	—	10	3	84	3·3	850	6,864	4,138	2,080	1,254	$\frac{1}{2}\times\frac{1}{2}$

---

* In this table, as it appears in Mr. Douglass's report to the Trinity Board, dated April 23, 1877, these columns are headed "Condensed Beam" and "Diffused Beam." In the copy of the same table as given in Mr. Douglass's paper, read at the Institution of Civil Engineers, March 25, 1879, the same columns are headed "Maximum" and "Mean" respectively.

In the photometric measurements of the Trinity Board, the standard of comparison was the 6-wick colza-oil lamp of the Board, and it was placed at a distance of 100 feet from the electric lamp. It was found that when two of Siemens' machines were coupled together, they gave a larger candle-power than when worked separately. Working separately the aggregate light was equal to 12,403 candles, while the illuminating power rose to 14,134 candles when the machines were joined to one cable and driven at the same speed as before.

Measurement of Incandescent Light.—To obtain accurate comparisons of the light powers of the incandescent lamps has been found to present no difficulty.

CHAPTER XII.

MATHEMATICAL NOTES.

Dr. Hopkinson's Investigations.—Dr. Hopkinson, in April, 1879, read a valuable paper on "Electric Lighting" before the Institution of Mechanical Engineers. In this communication he gives the results of experiments on one of Siemens' continuous-current dynamo machines to establish the relation between the electro-motive force, resistance of the circuit and current, and also between the energy transmitted, measured by dynamometer, and that appearing as current. The curve formed by taking the current as abscissæ and the electro-motive force as ordinates when different resistances are in circuit, is given, the quantities being reduced to a common rate of 720 revolutions a minute, it being taken that electro-motive force, with the other elements constant, is proportional to the speed. From this curve, now generally known as the "characteristic" of the dynamo, various problems can be solved. It will determine what current will flow at any given speed of rotation of the machine, and under any conditions of the circuit, whether of resistances or of opposed electro-motive forces.

Mr. Schwendler's Experiments.—With regard to the relation of speed to currents and electro-motive force, Mr. Schwendler* states: "The current produced by a

---

* Précis of Report to the Board of Directors of the East India Railway on electric light experiments.

dynamo-electric machine through a given constant total resistance in circuit increases permanently with the speed of the induction cylinder. This increase of current for low speeds is more than proportional to the speed; afterwards it becomes proportional, and for high speeds the increase of current is less than proportional to the speed. The current has, however, no maximum for any speed, but reaches its greatest value at an infinite speed. This same law, as the total resistance in circuit is supposed to be constant, of course holds good also for the electro-motive force."

With regard to the influence of external resistance, Mr. Schwendler further states: "Keeping the speed constant, the electro-motive force decreases rapidly with increase of external resistance. This decrease is more rapid the smaller the internal resistance of the machine. Hence the currents must decrease much more rapidly than proportional to the total resistance in the circuit. As in the case of speed the electro-motive force has no maximum for a certain external resistance, but approaches permanently its greatest value for an external resistance equal to nil."

Relation between Magnetisation and Speed in the Dynamo Machine.—Professor S. P. Thomson,[*] in a paper on "The Conditions of Self-excitation in a Dynamo Machine," communicated to the Society, arrived at the conclusion that in a well-built dynamo, where C is the number of conductors counted round the periphery of the armature, n the number of revolutions of the armature per second, N the whole number of magnetic lines (in C G S units) which traverse the armature, i the current in the circuit, S the number of convolutions in series with the main circuit, E R

---

[*] Note read before the Physical Society, January 26, 1889.

the sum of the electric resistances (in C G S units) of the circuit in which the E M F operates, and $E\rho$ the sum of the magnetic resistances in the magnetic circuit; the equation of E M F is

$$n\,C\,N = E\,R\,i,$$

and the equation of magneto-motive force is

$$4\pi S\,i = E\,\rho\,N,$$

from which by multiplication together,

$$4\pi S\,n\,C = E\,\rho\,E\,R,$$

or the product of the magnetic and electric resistance is constant for a definite speed of rotation. The last equation gives the means of determining the limit of self-excitation when the speed was altered by a definite amount, for the equation may be written

$$\frac{4\pi C S}{E R} = \frac{E\rho}{n},$$

showing that self-excitation will continue until resistance to magnetism is proportional to the speed.

Mr. Alexander Siemens' Paper at the Society of Telegraph Engineers.—Mr. A. Siemens has pointed out,* that in the ordinary dynamo machines as generally used, "the intensity of the magnetic field in which the armature revolves varies very much, being greatest when the external resistance is smallest, and *vice versâ.* If, therefore, the lamps producing the light are not working very regularly, their action re-acts continually on the machine in the most unfavourable way, by weakening the magnetic field when the resistance is greatest and the current most wanted, and by inducing the most powerful currents when the least resistance is to be

---

* *Journal Soc. Tel. Eng.*, March, 1880.

surmounted." This often destroys the insulation of the wire.

To obviate this the electro-magnet circuit has been made a parallel circuit to the external resistance circuit, one circuit acting as a shunt to the other. In this case, as the external resistance increases the E.M.F. rises, as more current passes through the electro-magnet circuit.

But although this causes the E.M.F. to vary in the right direction, it still causes fluctuation, and the variation in the strength of the field-magnets causes a variation in the power absorbed, and also displaces the most favourable point for the brushes.

A constant and permanent magnetic field is therefore recommended by using a separate machine for exciting the electro-magnets.

It is also pointed out that length of leading wires, by adding to the resistance of the circuit, diminishes the fluctuations in the current caused by the variation in the resistance of the arc.

Alternate-current machines appear, according to Mr. Siemens, to stand wear and tear better than the continuous-current machine, and in those made by Mr. Siemens an important improvement has been introduced by omitting the iron cores of the revolving coils. The heating effects of the cores caused by the incessant reversing of their polarity is thereby avoided, and the intensity of the magnetic field scarcely affected.

Mr. Fitzgerald's Investigations.—Mr. Fitzgerald argues that there is no force in nature varying simply as the number of cells in series of a battery or corresponding with what is known as electromotive force, and no inertia varying according to what is defined as electrical resistance.

Further, it is observed that the effects of varying those "current elements" are very different in the two cases of the dynamo-electric and the voltaic currents. The law of Ohm, as previously applied to the current effects of voltaic batteries, was thought by some to be inapplicable in certain points to the dynamo-electric machine and its currents. This does not mean, however, that the well-known law of Ohm is incorrect as a law of phenomena—an expression indicating a necessary relation—but from a physical point of view as empirical as other mathematical laws in which causation is lost sight of.

In the case of any electro-motor the equation $I = \frac{E}{R}$ is perfectly applicable. In the voltaic battery, however, a variation of R does not of necessity affect E, which is altogether independent of such variation when this occurs in the external portion of the circuit. Thus we have generally $I \propto \frac{E}{R}$, or current varies inversely as the resistance in circuit.

A variation of E does not necessarily affect R; and, when the external resistance of the circuit bears a high ratio to the battery resistance, a variation of the electro-motive force from E to E^1—an addition to, or diminution of, the number of cells in series—causes the current to vary approximately in the ratio $\frac{E^1}{E}$. Accurately, the variation in any case is determined by the ratio $\frac{E^1 R}{E R + F \rho}$, where ρ is the resistance of the cells added or subtracted. Thus,

$$\frac{E}{R} \times \frac{E^1 R}{E R + E \rho} = \frac{E^1}{R + \rho}.$$

In the case of a telegraph circuit for instance, we have approximately $I \propto E$. On the other hand, in the dynamo-electric machine, converting into electrical work a given horse-power, $I \propto \frac{1}{\sqrt{R}}$, since, the ratio $\frac{E^2}{R}$ being constant, $E^2 \propto R$, $E \propto \sqrt{R}$, and $\frac{E}{R} \propto \frac{\sqrt{R}}{R} = \frac{1}{\sqrt{R}}$. Thus any variation of R in this case necessarily affects E.

Again any variation of E necessarily affects R; and, the product $E I$ being constant, we have $I \propto \frac{1}{E}$, a somewhat startling result, which, to some observers, has appeared contradictory to the law of Ohm. With this, however, it is in perfect accord—in effect, since $E \propto \sqrt{R}$, $R \propto E^2$, and

$$\frac{E}{R} \propto \frac{E}{E^2} = \frac{1}{E};$$

or, when E is varied, the current varies inversely as the electro-motive force, because the resistance varies as the square of this value.

It will be seen that $R \propto E^2 = \frac{1}{I^2}$, and that the same quantity of work will be done by the current whatever may be the resistance in the circuit.

If h. p. be taken to express the total horse-power converted into electrical work (in the whole circuit), under the best conditions, with a Gramme machine of the form experimented with at the Franklin Institute,

$$\text{H. P.} = \text{h. p.} \times 1{\cdot}39,$$

and the efficiency of the machine is expressed by

$$\frac{\text{h. p.}}{\text{H. P.}} = \cdot 72 \text{ nearly.}$$

Or the machine can convert into electrical work 72 per cent. of the energy expended upon it.

Let E = electro-motive force, in volts, acting in a circuit.

R the total resistance in ohms, of the circuit.

r = resistance of the voltaic arc obtained.

H. P. = h. p. of the prime motor working the dynamo-electric machine.

h. p. = the h. p. absorbed in the production of electrical work in the circuit.

λ = the intensity as standard candles, of the electric light so arranged as to illuminate equally in all directions.

Λ = intensity of the light in one particular direction; the light being arranged to give the maximum illumination (without reflectors) in this direction.

The energy of the current, or the mechanical equivalent of the work and heat produced by it *per hour*, will be

$$\text{W} = \frac{\text{E}^2 \times 2654}{\text{R}} \text{ ft.-lbs.} = \frac{\text{E}^2 \times 1 \cdot 18}{\text{R}} \text{ ft.-tons.}$$

Horse-power absorbed in the current

$$\left(\frac{\text{energy in ft.-lbs.}}{33{,}000 \times \text{time in min.}}\right)$$

will be

$$\text{h. p.} = \frac{\text{E}^2}{\text{R} \times 747}.$$

The ratio $\frac{\text{h. p.}}{\text{H. P.}}$ is the measure of the efficiency of dynamo-electric machines. In the case of Gramme's machine, under the best conditions we have

$$\text{H. P.} = \text{h. p.} \times 1 \cdot 39.$$

The horse-power absorbed in the arc itself is

$$\text{h. p.} \times \frac{r}{R}.$$

The ratio of this latter value to h. p., or

$$\frac{r}{R} = \frac{\text{h. p.} \times r \times 747}{E^2}$$

is the measure of the efficiency of the electrical circuit in the production of the greatest quantity of light with a given quantity of electrical energy.

In the experiments with the Gramme machine made by the Committee of the Franklin Institute, the light, in standard sperm candles, produced by the voltaic arc was

$$\lambda = \text{h. p.} \times \frac{r}{R} \times 1{,}044 \text{ (candles)} \;.\;.\;. \text{ (I)}$$

when the intensity of the light was approximately equal in every direction. But, when the carbons are so adjusted as to give the best effects with the photometer in a given position, we may multiply the former value by 2·87, and we have

$$\Lambda = \text{h. p.} \times \frac{r}{R} \times 2{,}996 \text{ (candles)} \;.\;.\;. \text{ (II)}$$

Expressing these equations in a different form, we have

$$\lambda = I^2 r \times 1{\cdot}4 \;.\;.\;.\;. \text{ (I}a\text{)}$$

$$\Lambda = I^2 r \times 4 \;.\;.\;.\;. \text{ (II}a\text{)}$$

It should be remembered that these values are obtainable only under the most carefully arranged conditions.

Although the light cannot be subdivided without very considerable loss, it is not to be admitted that, if a given total quantity of light be produced with one hundred lamps, it is one hundred times as expensive as if it were produced by one lamp. If we use two lamps instead of one, and put them in series, the original arc resistance, l, is not necessarily doubled; indeed it may be preserved constant, in which case we should have $\frac{C^2 l}{2}$ for each light, and the original value, $C^2 l$, for the two. And if we place four lamps in parallel circuit, the total resistance may be reduced nearly fourfold, so that we may obtain twice the original current with half the electro-motive force in action. Thus

$$C^2 l, \text{ or } \frac{E^2}{l^2} l \text{ becomes}$$

$$\frac{\left(\frac{E}{2}\right)^2}{\left(\frac{l}{4}\right)^2} \times \frac{l}{4} = \frac{4 E^2}{l^2} \times \frac{l}{4} = C^2 l.$$

The theoretical value for each light being

$$\left(\frac{C}{2}\right) l = \frac{C^2 l}{4},$$

and that from the four $C^2 l$. The loss, when the light is subdivided, is doubtless due to an increase in the quantity of heat which must be expended before any luminous effect is produced.

Equational numbers required in reducing results.— The particulars given herewith will be found of value in any experiments upon dynamo-electric machines, circuits, or lamps.

One horse-power is equal to 1,980,000 foot-lbs. per hour, or 33,000 per minute; that is 33,000 lbs. weight falling one foot in a minute, or 1 lb. weight falling 33,000 feet per minute.

1 horse-power is maintained in modern steam-engines with 3½ lbs. of coal per hour.

1 heat unit = 772 foot-lbs.

Therefore 1 horse-power = 2,565 units of heat per hour, and $\frac{2565}{380} = 6\frac{3}{4}$ units of heat per candle of light.

1 standard candle (of sperm) burns 120 grains per hour, and equals $\frac{1}{3}$ cubic foot of gas per hour.

1 lb. gas coal produces 4 cubic feet of gas, 0·85 lb. of gas coke, and 0·05 lb. of tar. In a pound of gas coal there are 15,000 units of heat, in the coke 13,000, in the gas tar 20,000 units of heat.

The power expended by a dynamo-electric machine producing current for the light of a standard candle is about 90 lbs. falling through one foot in a minute.

1 calorie (kilogramme of water heated 1° Centigrade) is equal to 424 kilogrammètres, which equals 3·9683 units (Fahrenheit).

1 kilogrammètre equals 7·2331 foot.-lbs.

The electrical units employed at present may, for practical purposes, be taken as follows:—

The *Volt* is the unit of electro-motive force, and is nearly equal to the electro-motive force of a Daniell element, the latter being about 1·079 *volts.*

The *Ohm* is the unit of resistance, and equal to 485 mètres of pure copper wire one millimètre in diameter at a temperature of 32° F.

The *Ampère* is the unit of current, and is the current that would be produced by an electro-motive force of one volt, acting through a resistance of one ohm.

Ohm's Law of the Circuit.—The famous law discovered by Dr. G. S. Ohm expresses very clearly and simply the relation of the three units, volt, ohm, and ampère, to each other. It shows that *the current is directly proportional to the electro-motive force exerted in, and inversely proportional to the resistance of the circuit,* or, as it is usually put, in the form of an equation:—

$$\frac{\text{Electromotive force (volts)}}{\text{Resistance (ohms)}} = \text{Current (ampères)}.$$

These numbers are generally expressed in symbols, using E for electromotive force, R for resistance, and C for current.

$$\frac{E}{R} = C.$$

The law is also written

$$R = \frac{E}{C},$$

or

$$E = C \times R.$$

The word "Pressure" is now coming into general use by practical men in lieu of electromotive force or potential. It is not strictly correct, and may lead to false views of what is going on in the circuit.

Conductivity is the inverse of resistance. Different substances show different conductivities. Thus, taking silver as possessing a conductivity of 100, copper shows 96, while iron only gives 16.

The resistance of a conductor varies directly as its length. Its resistance varies inversely as the area of its cross section.

The Board of Trade Unit.—Under the provisions of the Electric Lighting Act, the Board of Trade has issued certain regulations, in which the electrical unit authorised in the transactions between electric light companies and consumers is defined as *one thousand watts*,* maintained for one hour, termed a Kilowatt-hour. Such a current would maintain an ordinary 50-volt lamp alight for twenty hours. The cost of such a current in England varies to the consumer from 1s. down to 7d. The cost at the generating station is said to be as low as 3½d.

---

* "Watt," p. 5.

CHAPTER XIII.

PRESENT APPLICATION AND COST OF THE ELECTRIC LIGHT.

SO extensive has been the introduction of electric light, that to enumerate the installations and dwell upon them in detail would in itself almost fully occupy the pages of this little treatise. One or two of the more noteworthy instances can only, therefore, be briefly glanced at.

Lighting by Incandescence.

Dwelling-houses.—Since incandescent lamps have come into use, no particular distinction between the disposition of the lights and gas-burners can be drawn. For decorative or artistic purposes, however, the incandescent system places at the disposal of the artist a wonderful source of striking effect. The glow lamp may be placed in situations and positions impossible with gas. It may be connected to a long, flexible conductor and carried about a room, &c.

Shops and Warehouses.—The general lighting of shops and warehouses is still largely carried out upon the arc system. This is, no doubt, due to the greater cheapness of the arc light as compared with glow-lamps. But for window decoration the glow-lamp is coming into extensive use. It presents the great advantage of being semi-portable, and it may be placed in positions and among goods where gas or oil lights would be dangerous. But it must not be supposed that a glow-lamp is perfectly safe if placed in contact with inflammable goods. Experiments have proved that it may be possible to char or ignite dry materials when in contact with a glow-lamp in full light. Of late the two systems of arc and incandescence have been used in combination in warehouses with satisfactory results.

Theatres.—It is now well known that theatre lighting is much less costly, when the insurance charges are considered, in the case of electricity than in that of gas. The greater safety, the diminution of heat, the purer atmosphere, and illumination, all tend to the rapid introduction of the incandescent system. It is used both before and behind the curtain, and in some cases even in the decoration of the actresses. The disposition and arrangement of the glow-lamps is now so generally well known that it will be unnecessary to enter into particulars here. The Savoy Theatre, London, owing to the enterprise of Mr. D'Oyly Carte, was the first of its kind to be entirely lighted by incandescent lamps in this country. It was lighted for the first time by electricity on the evening of the 10th October, 1881. Messrs. Siemens Brothers were the engineers. The stage is lighted by 715 clear glass lamps, and may be lighted at will by coloured lamps instead, blue being the tint used for night scenes. The change is made by the movement of a switch. The brilliancy of either set of lamps may be regulated at will by inserting, or withdrawing from, the shunt circuit feeding the field magnet of the dynamo, certain resistances. This arrangement is also under the control of the stage manager, and from the switch-box at the corner of the stage any change may be made. The lamps are carried upon battens of incombustible material, and are movable at will to answer any change of the scenery. The building before the curtain is lighted by 150 glow lamps, arranged in groups of three, each lamp being enclosed in a ground-glass globe. The refreshment-rooms, offices, and corridors are lighted by 165 lamps; the dressing-rooms behind the stage by 148. The lamps are placed in the usual multiple arc or parallel system upon three independent circuits, maintained by three Siemens dynamos, each yielding 400 ampères at 93 volts. For several years these were driven by two Marshall portable engines of 20 horse-power, and one Roby engine of similar power. About 150 horse-power is usually required to illuminate fully the whole of the lamps. This installation, which is now combined with the larger one supplying the Savoy Hotel, has continued to work without serious hitch from the commencement. Its success has doubtless led to the present extensive introduction of the incandescent system into the London theatres, numerous examples of electric lighting in which, supplied from central stations and from private machines, are now to be found.

Incandescent Lighting of Large Spaces.—There is every prospect of an extensive introduction of glow-lamps of high candle-power for out-of-door works of magnitude, and for large spaces generally. Since the perfecting of lamps of 1,000 and 1,500 candle-power, they have been taken up in preference to the arc or the "lucigen" oil light. Such lamps are frequently run in series. They present the great advantages of diffusing the light and of requiring no attention.

Incandescent Lighting of Railway Trains.—Ever since the incandescent lamp became sufficiently perfect for general purposes, great expectations have been entertained by the travelling public that at last the question of effectively lighting railway carriages would be solved. But it is not a little curious that it cannot yet be said that railway companies have interested themselves sufficiently to make use of so perfect a source of light as the electric current. The London and Brighton Company have from the first occupied a foremost place in the electric lighting of their trains. They were the first in this country to use the new secondary batteries for that purpose, and for years ran particular trains so fitted, removing the accumulators and recharging as required. It may, indeed, be said that this company have never ceased to experiment on the subject, and that they are now further advanced in electric lighting than any other company in this country. They have at the present time nearly twenty trains lighted in this way, having surmounted the difficulties experienced by other companies.

At the recent meeting of the International Railway Congress, a comprehensive report on the subject was presented by the management of the Belgian State lines. The different sources of electricity tried were: (1) Primary batteries; (2) accumulators, placed (*a*) in the van or baggage car; (*b*) in each car, so as to render the lighting independent; (3) a dynamo connected to one of the axles, with accumulators to keep up the lighting when the train is at rest; (4) a dynamo operated by a special motor, placed on the locomotive or baggage car, and supplied by steam from the engine or separate boiler.

Some of the difficulties to be surmounted are:—if the supply be from a single source for the whole train, dividing the train cuts off the cars from the light. Apart from the separating of trains there is the difficulty, if the current comes from a dynamo run from the axles, that the light ceases when the train stops. Extensive experience has proved that the best system yet known is the use of a small dynamo in the van, driven by special gear from the axle, and in connection with this a sufficient number of accumulators to light the train when the dynamo is stopped. Special arrangements are made that the dynamo is not driven the reverse way when the train happens to be backed, and several sets of gearing are in use that ensure the moving of the dynamo in a uniform direction independent of the direction the train is travelling. Again, arrangements must be provided for preventing the accumulators from discharging themselves back through the dynamo when the latter is stopped; and it is further necessary to compensate for the different speeds at which the dynamo runs, so that its E. M. F. may suit the number of cells in use.

The accumulators are placed usually in one battery, under or in the van, in the case of a train that runs regularly without being broken up. If the train is liable to disjunction, each carriage has a few cells to itself, which will maintain the light for several hours, apart from the assistance of the dynamo. In this way the London and Brighton, and the Great Northern, and Midland Railways have several trains constantly lighted by the electric light. The lamps are generally 8 or 10 candle-power Swan lamps, two being usually employed in the roof of each compartment. In some of the Midland express trains four such lamps, placed at opposite corners of the compartment, behind the travellers, are employed, situated behind ground-glass lenses.

An ingenious application of the electric light for tunnels is made use of at Glasgow, where the day trains are lighted while passing through the tunnel by a current taken by brushes from a central fixed rail between the regular rails. This electric rail is insulated and connected to one pole of a dynamo. The other pole of the dynamo goes to earth. The return current from the train passes to the rails, through the wheels, and so to earth.

Railway managers urge the cost of the electric light as precluding its use in ordinary trains. It is said to be twice as expensive as oil or gas. But it is sufficiently evident that as soon as a perfectly workable system is established, its universal use in railway carriages is only a question of time.

Interior Illumination of Large Buildings by Arc Light.—Such places as halls, workshops, and picture-galleries are most effectually illuminated by arc lights from above. There are various methods of accomplishing this object and of diffusing the light. Perhaps the best is that of sending the full rays through a large sheet of frosted glass.

This should be set in the centre of the ceiling, if convenient at the same height as the ceiling. Its size will depend upon the size of the building. For a medium-sized lecture hall, a glass surface 6 feet square will be found sufficient. Directly above this frosted glass surface is to be placed the electric light. The lamp should be hung by a cord and counterpoise. According to the form of lamp used, it may be necessary to reflect the light downwards from it by means of wooden covers, about 6 feet square, covered with sheets of tin plate. Two of these will be found sufficient. They should be set at an angle, rising from the edges of the frosted glass until quite over the lamp. Any rays then thrown upwards will be reflected upon the frosted glass.

Light sent over a building in this way is beautifully diffused, and is very soft and agreeable. It will be necessary to have free access to the lamps from above. In some cases it will be found very advantageous to enclose the lamp in a ground-glass case, and to suspend this near to a white ceiling. But a better plan still is to have a pyramidal case of ground-glass made, to fasten the base of this to the ceiling, and to lower the lamp into it from above. The result is perfect diffusion of the light, which must of course be reflected downwards into the glass case by reflecting boards or a whitened ceiling.

Workshops are frequently illuminated in France by setting the lamp over a reflector on the floor, screened by some cover, and projecting the rays from the reflector upon the whitewashed ceiling. This is what is usually done, and is found to answer the purpose very well. A great objection to the Serrin and such lamps is the base containing the movement, which, when the lamp is suspended, throws downwards a great deal of shadow; but this is entirely prevented by the use of slanting reflectors.

In the extensive chocolate works of M. Menier the Serrin lamps are in use, and the proprietor has devised a means of access to the suspended lamps without the use of ladders or a separate suspension cord. A windlass is used, having a dry wooden drum with cast-iron cheeks. A cable with two insulated and stout wires is made fast to the drum, and the ends of it to the cheeks; this cable leads upwards to the roof, over a pulley, and on the other side hangs the lamp. It can thus be lowered by the windlass with ease without in any way disturbing the connections. The cheeks of the winding drum are, of course, connected to the terminals of the dynamo-electric machine through the separated bearings.

Electric arc lights are in extensive use in all out-of-door works of magnitude, such as bridge and dock construction, and it is found, as was proved in the case of the great Tay bridge, that operations may be carried on at night with the greatest facility. For such purposes, the light should be so arranged that a power of about 2,000 candles is thrown around every 600 feet of space—that is, an ordinary 2,000 electric light, placed upon a 20-feet standard, should give sufficient illumination at a radius of 300 feet. In some cases the standard is thus inadmissible, and the light may have to be thrown upon the work from a parabolic reflector. All such lights should be enclosed simply in a clear glass case to screen them from the wind.

The use of ground-glass cases for these purposes, and above all opalescent glass of any density, should be avoided as much as possible. A great deal of light is thus lost in the Jablochkoff system. It has been found from experiment that

Plain glass absorbs about	10 per cent.
Ground or frosted	30 ,,
Thin opalescent	45 ,,
Thick ditto	60 ,,

When the light is any considerable distance from the machine, the cables carrying the current should be thick and of good copper, and every means thus used to reduce the resistance of the conductor outside the machine, more especially when a lamp with long carbons, and consequently much resistance, is employed.

The use of the electric light in our lighthouses is a matter of great importance, but not of special interest to the general public, so that, with the exception of what has been said in connection with the experiments on dynamo-electric machines, it need not further occupy space.

For use aboard ship, and for war vessels especially, a very useful apparatus is manufactured by Messrs. Sautter and Lemonnier. It is a lenticular projector, with a Fresnel lens, composed of three dioptric and six catadioptric lenses. The Serrin lamp is placed behind the system, which is mounted on an iron stage, movable around its vertical axis, and turning upon its horizontal axis, so that the light has great range, and may be concentrated upon one point anywhere around the vessel. The whole is enclosed in a cylinder, opaque behind; and a small camera lucida is so placed in it as to throw the image of the carbon points upon a ground-glass screen, so that their condition may be noted without opening the cylinder. The three-cylinder Brotherhood direct engine is usually employed to drive the machine in conjunction with such apparatus. Of the many excellent engines, combined with dynamos in use aboard ship, mention should especially be made of Messrs. Clark, Chapman & Parsons' combination, called a Turbo-electric generator, consisting of a steam turbine and dynamo connected direct, and particularly well suited for use aboard ship.

Cost of Electric Light.

In entering upon a consideration of this aspect of the question the greatest care is necessary in order that the data may be of a thoroughly trustworthy character. The subject divides itself into two great branches—the cost of lighting by incandescence and by arc lamps.

Cost of Lighting by Incandescence.—As in the production of most other commodities, the *scale* upon which electricity is generated bears very strongly upon the cost to the consumer.

Locality, price of coal, distance of consumers from generating station, and lastly, the *system* employed, will each and all influence the cost of the current.

The Board of Trade unit, consisting of a kilowatt-hour (a thousand watts for one hour), is the recognised standard of calculation. Extensive experience of the high tension transformer and other systems in England has shown that the kilowatt-hour can be sold at a fair profit at from 7d. to 9d. For some time to come it will probably average at 8d. It is estimated that the actual cost of electricity from a station capable of maintaining 20,000 lights should be as low as 3d. per unit, or equivalent to gas at 1s. 8d. per 1,000 cubic feet. The price to consumers at 8d. would be equal to gas at 4s. 7d. per 1,000 cubic feet. It is probable that a dividend of 10 per cent. could easily be paid by such a supposed station, serving customers at within a radius of two miles. These figures are now realised at several stations in London. Consumers are charged by meter. An average glow-lamp takes from 2½ to 3½ watts.

Two notable instances of central-station distribution on the Continent pay a good dividend at the following prices for 16-candle lamps: 0·48 of a penny per hour and 0·4 of a penny per hour. The former price prevails in Berlin, the latter in Milan. In Berlin the charge per lamp for installation is 6s., in Milan it is 28s. The charge for hiring meters is rather high, being 16s. per annum in Berlin, and 4s. 10d. in Milan.

Thus, it will be observed that the question as to the relative price of gas and electricity will vary greatly in different places. In Berlin, where gas is 4s. 9d. per 1,000 cubic feet, the electric light will be a trifle dearer. In Milan it is 5s. 8½d., so that the electric light is the cheaper there. In London the electric light at the figure given is slightly dearer than gas. In the country, where gas is frequently sold at 2s. 6d. per 1,000 feet, the electric light would be very much the dearer. But, as a matter of course, when gas is cheap, power can be produced at a reduction upon the calculation; and the cost per unit at the generating station, instead of being 3d. (the cost in London), would probably be 50 per cent. less, so that electricity may be expected to compete effectively with gas, especially since glow-lamps have so much to recommend them over gas flames.

Cost at the Athenæum Club.—378 glow-lamps. Dynamo is worked by a *gas* engine. Cost for the year 1887, £959 1s. 9d. The average cost of inferior lighting by gas and oil previously used was £840. The gas consumed by the engine cost £446 7s. 10d.

Cheapness of the Arc Light.—The very high candle-power of the electric arc per horse-power places it, in respect of cost, in a position far below the average price of gas. The incandescent system is much more expensive.

Cost of the Incandescent and Arc Lighting at South Kensington Museum.—General Festing's report to the Science and Art Department upon the cost of the mixed system in vogue at the Museum shows that the working expenses amounted to £1,224. If the same portions had been lighted by gas, the cost would have been £2,845. There was thus, concludes the report, a saving of £1,621, which is 50 per cent. on the cost of machinery and apparatus. 860 16-candle glow-lamps are used here.

Street Arc Lighting.—The quotations for street lighting by different companies are found to vary considerably. In one instance, the average of several tenders, for lamps of 1,200 candle-power, burning six hours nightly, was £17 7s. 6d. per annum. (Lighting of Taunton.)

Mr. A. Siemens, in his paper read before the Society of Telegraph Engineers, March, 1880, gives the following particulars as regards comparative cost of electric light and gas. In making the comparison it is assumed that a 100-candle Sugg gas-burner will consume 23 cubic feet of gas per hour, costing 3s. 6d. per 1,000 cubic feet; further, that a 400-candle alternate-current light requires ½ horse-power, and that it consumes 3 inches of carbon per hour, costing 4½d. per foot; and that a 6,000-candle continuous-current light requires 4 horse-power, consuming 3 inches of carbon per hour, costing 8d. per foot. When the electrical machines are driven by a gas-engine consuming 26 cubic feet of gas per hour per horse-power, the relative cost of maintaining a light of 6,000 candle-power is as follows:—

For gas . . . . 4s. 10d.

For alternate-current electric lights (fifteen 400-candle lights):—

	s.	d.
200 cubic feet of gas for the motor	0	8½
3 feet 9 inches of carbon, at 4½d. per foot . .	1	4½
Attendance	0	6
	2	7

Showing a saving of 47 per cent. over gas.

For continuous-current light:—

	s.	d.
114 cubic feet of gas for the motor	0	4½
3 inches of carbon, at 8d. per foot	0	2
Attendance	0	1½
	0	8

Showing a saving of 87 per cent. over gas.

At the Albert Hall a saving in gas is effected of 25,000 cubic feet per night, or £4 7s. 6d., while the five electric lights cost £1 10s. 6d. for fuel, attendance, and carbons. In this case a considerable expense is incurred with the pumping engine which is used for driving the machinery, and which consumes a very large quantity of fuel. Nevertheless a saving of 66 per cent. is effected.

At the British Museum the electric light was used for 360½ hours between 28th Oct., 1879, and the end of February, 1880. Two 8 horse-power engines are used. There are four lights in the Reading-room, of 4,000 candle-power each, and in the halls seven of 400 candles each. There are four continuous-current machines for the Reading-room lamps, one to each lamp, in separate circuits. One alternate-current machine works the other seven lights. Another machine of continuous-current type excites the electro-magnets of all the other five. The machines are tried in the morning, and then the fires of the engines are banked up so as to be ready at ten minutes' notice.

The cost for 360 hours is as follows:—

	£	s.	d.
Carbons	50	15	10
23 tons of coal, at 15s.	17	5	0
18 gallons of oil, at 4s. 6d.	4	1	0
54 lbs. of waste, at 6d.	1	7	0
2 sets of brushes, at 5s.	0	10	0
1 set of commutator plates	0	17	6
Engine-driver, 18 weeks at 37s.	33	6	0
Total cost	£108	2	4

This gives us cost per hour:—

	s.	d.
For carbons	2	9
Other charges	3	3
	6	0

This is a cost of not more than 6s. an hour for a light of 18,800 candles; which amount of light produced by gas would cost at least 15s. per hour, the saving effected being 60 per cent.

The following facts as to the lighting of the Thames Embankment will be of interest. The first experiment, with 20 lights, was commenced on the 13th of December, 1878; the second, with 40, on the 16th of May, 1879; the third, with 55 lights, on the 10th of October, 1879. The length of the circuit on the west side of Waterloo Bridge was 6,007 ft.; of that on the east side, 6,062 ft. The total length of conducting wire was 17 miles 361 yards. The ten new lights on Waterloo Bridge were worked by a 20-light Gramme machine in two circuits.

CHAPTER XIV.

NOTES ON SHIP LIGHTING.

INCANDESCENT electric lighting has proved itself superior to every other tried means of illuminating ships. Not only have passenger steamers adopted the light, but the owners and crews of trading vessels of all kinds have found it the most acceptable of all the modern improvements lately introduced in the fittings of a ship.

Source of Electricity Used.—As in the case of installations ashore, the motive power of the steam-engine has been found the most suitable source of electric energy at sea. It may be supposed that in cases when the light is installed aboard steamers, having unlimited power to spare from the propelling engines, this source of motion might be utilised for the driving of a dynamo to supply the necessary current. But there is scarcely an electrically lighted steamer afloat where this is done. Although it was tried in the early history of ship lighting, it was speedily found that ship-propelling engines are subject to fluctuations of speed more marked than in any other application of steam power. In rough weather the screw engines may be observed to run at every degree of velocity, from zero to maximum, within a few minutes of time. When the propeller is buried deep in a cross sea the speed of the engine is very slow. When the propeller is raised almost clear of the water, as it frequently is in a rough sea, and the vessel is pitching, the engine speed is usually so high that it is known as "racing." In fact, in a heavy sea the engineers are careful to obviate the evil effects of racing (which if unchecked will violently shake the ship from stem to stern) by a system of steam "throttling."

These observations will serve to show that a dynamo driven from the main engine would not yield a current suitable for incandescent lamps, when we reflect that a drop of five per cent. in the speed will cause the lamps to appear decidedly dim, and a rise of five per cent. to cause them to burn with undue brightness.

The accumulator is an admirable regulator when the speed of the dynamo is liable to vary somewhat, but the excessive variation in the velocity of ship's propelling engines has been found to be all too great for this purpose. Accumulators have, however, been kept charged by dynamos driven from main engines, but this cannot be depended upon in rough weather. It is in the nature of an accumulator that it will send a counter (or back rush) current through the dynamo if the latter happen to fall off in E. M. F. by a diminution of speed. This involves the use of complex automatic or hand regulators, the former of which cannot always be relied upon.

Small high-speed separate engines are therefore generally employed for moving the dynamos. These engines may be regarded as a class by themselves. They are usually bolted to the foundation-plate of the dynamo, and the engine and dynamo shafts being coupled together form a common axis. This arrangement is very compact. Steam is taken from the main boilers, where a constant pressure is maintained.

The dynamo most suitable for ship lighting, when an ordinary engine as above is employed, is a slow-speed compound wound machine, working at an electro-motive force of about 60 volts. When the shunt and series windings of the machine are properly proportioned such a dynamo may be regarded as self-regulating, *e.g.*, its output is in proportion to the number of lamps burning. This class of machine is now known as a constant-potential dynamo. The shunt coils should be sufficient to excite the machine when the lamp circuit is open. The series coils are short and thick, and are intended merely to maintain the *potential*, which is apt to fall as more and more lamps are switched into circuit, and as the current increases. Such a dynamo to be effective must have wrought-iron electromagnets, and be otherwise carefully designed. It is a very great convenience aboard ship.

Accumulators Aboard Ship.—A considerable proportion of the vessels fitted with the electric light carry accumulators. The storage battery is useful for maintaining the "all-night" lights, the masthead and side lights, &c., when the dynamo is not running; it is also an efficient regulator. Large batteries of accumulators are not, for several reasons, adapted for ship work. The maximum number should not generally exceed twenty-six cells (sufficient to run 50 volt lamps). Ship accumulators are generally fitted in teak wood cases. These are made of extra depth, to obviate splashing over of the electrolyte, and generally call for more careful attention than cells kept in a horizontal position.

Ship Wiring.

The leading peculiarity of ship circuits lies in the fact that in most instances the iron body of the vessel is utilised as a return, and that only one wire is employed to feed the lamps.

A good deal of objection has been urged, and not without reason, against this practice. It involves extra insulation of the leading wires, for by dispensing with the return wire the insulation resistance is practically halved, and there is constant danger of short circuits, unless the work be carried out in the most approved manner. Apart from the risks of short circuits and leakage, we have to consider the inductive influence the currents in the main leads are apt to have over the compasses carried by the vessel.

Sir William Thomson* has drawn attention to this subject, and cites various examples of disturbance of compasses by the electric lighting current. He further advocates the employment of the two-wire system, as used in buildings, with the conductors as near together as practicable. It may be pointed out, however, that if an alternating current be used instead of a constant current, there will not be any inductive influence upon the compasses, whether one or two wires be employed. But it has been shown by Mr. Siemens that in the cases where the compasses have been influenced, the conductors were run singly near to them, and without regard to induction. In cases where the leading cable is situated at a considerable distance from the compass, or is screened by the iron deck, no appreciable disturbance of the compasses is observed.

---

* Paper read before Institute of Electrical Engineers, May, 1889.

Test for Compass Disturbance.—Sir William Thomson has pointed out that the question whether the lighting current has any effect upon the compass may be settled before the ship leaves dock by merely putting on and off the light and observing the needle. A test is also taken after the compass has been artificially deflected (by means of a small permanent magnet hung near) to the extent of 45° from the normal.*

When the wiring of a ship for incandescent lamps is to be carried out upon the single wire system, the insulation resistance of the wires to be selected must be very high. In other words, the conductors must throughout be insulated with vulcanised india-rubber, and thoroughly protected from mechanical injury. The insulation must be twice as effective as that usually employed, and it must withstand continuous immersion in sea water. Joints must be efficient both with regard to conduction and insulation—in fact, the insulation joint must be in every way as good as the unbroken covering of the cable.

Cables are generally run as far exposed to view as practicable. It is always objectionable to conceal cables carrying currents of considerable strength. When run along the ship's shell, or under an iron deck, the wires are fastened with wooden cleats. A strip of varnished wood, or wood otherwise prepared against the absorption of moisture, is bolted to the ironwork in the course of the cable; the cleats are screwed to this. In every case the cable should be kept several inches from the ironwork, and must be so securely cleated down that an accidental contact would be impossible. A very general arrangement

---

* See *The Nautical Magazine* for December, 1885, and *Journal of the Society of Arts*, Feb. 5, 1886.

of the circuits in a passenger ship is to arrange for three separate branches, taken from the main switchboard in the engine-room. Two of these are run along the ship's sides, and the third takes a midway course.

Branch Wiring necessitates the greatest care, first, in making the conductive joint, then the insulation joint, and inserting the safety fuse. A fuse must be inserted at the root of every branch. These junctions, after completion, should be covered by small cast-iron boxes, with an opening sufficient to admit of the replacement of the fuse. "Return" wiring is dispensed with, but there must of necessity be a certain amount of short branch wiring before contact can be made to the body of the ship. These return wires may be of naked copper, and twisted together, from a group of lamps, afterwards making general contact to the ironwork. Stout studs for making contact are employed. They are secured to the ironwork, and are provided with connectors.

The negative pole of the dynamo, or accumulator, is put into metallic contact with the ironwork of the ship. A good connection must be insured. The piercing of bulkheads for the passage of cables requires some consideration. If cables can be taken to deck and down the other side, it will prove better than piercing a bulkhead. If a partition must be passed through it should be done as high up as possible. The channel for the cable must be lined with a porcelain or vulcanised rubber tube, and a watertight joint should be made by packing with asbestos and insulating compound applied hot.

Lamps.—50-volt 10-candle power lamps, taking about 30 watts each, are generally employed on board ship. It is not advisable to use a potential of 100 volts on the single-wire system. Lamps of the same voltage, but of greater candle power, are used when a stronger light is required. In the work of night loading an arc lamp is useful. The voltage of the dynamo being over 50, an arc lamp is commonly put across the leads in the same way (in parallel) as an incandescent lamp. Such a lamp may require a current of from 6 to 10 ampères. An *impedance coil*, frequently consisting of a simple copper resistance wire of about an ohm, is generally put in circuit with the lamp. The use of impedance coils on parallel systems is becoming general. It secures remarkable steadiness in the burning of the lamp. Of late an attempt has been made to obviate the waste that is incurred by the employment of a simple resistance. If a coil of this kind is made to encircle a core of soft iron the magnetic induction of the latter acts as an impediment (or damming back) to the current, without the waste incurred by a simple resistance. Such improved impedance coils are made much shorter and of less specific resistance than the older choking coils. Mr. Brockie believes that a properly constructed impedance coil can be shown to have but one-twentieth the resistance of a simple resistance coil exhibiting the same damming-back effect.

Area of the Cables.—When the electro-motive force is as low as 55 or 60 volts, the cables and branch wires must be of considerable effective sectional area. Most of the successful installations of the light aboard ship have been carried out on the basis of Sir William Thomson's suggestion to employ wires having a sectional area of one square inch for each 1,000 ampères of current carried. This is nearly one square millimetre for each ampère and a half of current. According to this rule the following numbers of lamps, each taking from 50 to 60 volts and from 1·5 to 1 ampère, may be safely run upon the wires:—No. 10 standard gauge wire, 10 lamps; No. 8 gauge, 15 lamps; No. 6 gauge (or which is more common, 7 No. 15 wires stranded in a cable), 20 lamps; 19 No. 16 wires stranded, 30 lamps; 19 No. 15 wires stranded, 50 lamps. The branching wires may be as fine as the following;—1 lamp, No. 18; 2 lamps, No. 16; 4 lamps, No. 14.

If the dynamo is situated amidships the cables will run fore and aft. A point should be found which is midway of the consumption of current; *e.g.*, if there are 100 lamps upon either half of the cables run the central portion is the "feeding point." This means that after the cables are fitted, feeders, consisting of thick cables, should be run from the dynamo to the centre of the points of greatest consumption to equalise the pressure. It is rarely that the end of a cable can be attached to the dynamo.

CHAPTER XV.

ELECTRIC LIGHT WIRING TESTS.

DURING the work of wiring buildings or ships for the electric light certain precautions must be taken to insure against the risk of fire, extinction of the light, and loss of power. This work is known as testing. It commences with certain tests of the conductivity and insulation resistance of the leading cables. While these are being laid the circuits are again tested for continuity. Their resistances should again be taken, and the results compared with the calculated figures. The taking of insulation tests cannot be too strongly insisted upon. There are two factors with which the electrical wireman must be familiar. These are the *conductivity* of his circuits and the *resistance* of their insulation.

It may be pointed out that, although a great deal of wiring has been carried out with no other test than that for continuity of conductor, such work cannot be reliable. The only thing that is known for certain about it is that it will convey a current. How much energy is lost in leakage, what incipient faults there may be, or what risks of overheating and fire are all unknown quantities.

In addition to the main tests certain minor tests for short circuits, or leakage from one wire to another, are becoming common.

Nature of Insulated Wire.—All the first-class makers of electrical wires can supply copper conductors having a conductivity as high as 98 per cent. of pure copper. This is the quality of wire that should be employed in house wiring. The insulation consists of various materials. In fact, the words *insulated wire* have far too wide a significance. A wire merely covered with a wrapping of cotton thread is not necessarily insulated. The best reliable class of "insulation" consists of a heavy cotton covering, either single or double. It is considerably improved by being soaked afterwards in an insulating or rubber varnish. But such covering is only at most suited for conveying a small current under a low electro-motive force (25 volts and 1 ampère).

A better class of covering is effected by wrapping over the cotton a tape, treated with rubber varnish. These low quality wires are of naked copper only.

Superior insulation consists, first, of tinned copper conductor, single or double cotton covered, then a lapping of pure india-rubber, followed by braided cotton or tarred flax, and frequently a further mechanical protection of heavy tape. The india-rubber covering is sometimes double. This constitutes insulated wire.

Cable insulation for indoor work frequently consists only of cotton tape, and braided tarred flax coated with insulating compound. The best class of both wires and cables are india-rubber covered, the india-rubber being afterwards vulcanised. The exterior covering is either cotton tape or tarred flax.

For ship wiring, to show a high insulation resistance, the conductor covering must be of the best. For house wiring where a low tension is employed (50 volts), the insulation may be lighter. Wires are tinned to obviate injury to the rubber and copper by contact.

Conductor Resistance Tests.—The apparatus generally employed for this purpose consists of the well-known Wheatstone's Bridge, by means of which either conductor or insulation resistance may be determined. Most working electricians are familiar with the bridge method, and there are several patterns of bridges in use. The most convenient is doubtless that in which the "bridge" is combined with sets of resistance balancing coils in one portable case. Such a portable testing set is usually accompanied with a testing battery of the Leclanché cells of small size. Thirty cells are generally considered sufficient even for insulation tests. The resistance balancing coils are either put into and out of circuit by means of connecting plugs, or by means of a movable switch revolving around a centre. The latter is considered the more convenient form. By the courtesy of the Messrs. Grey we are enabled to give a diagram of the new Silverton Wheatstone Bridge testing set, which is specially adapted for electric light work.

Fig. 149 represents diagramatically the arrangement known as the bridge. The theory can be fully studied by the aid of any good text book,* but it shortly consists in the obtaining of equilibrium by the adjustment of the resistances in A B and C D until there is no difference of potential between the points E and F, and consequently no deflection of the galvanometer needle when the key is closed. These conditions can only be obtained when the resistance in the two sides X B and C D A are equal, or bear certain proportions

---

* See p. 142 of Prof. J. A. Flemings' "Short Lectures to Electrical Artisans."

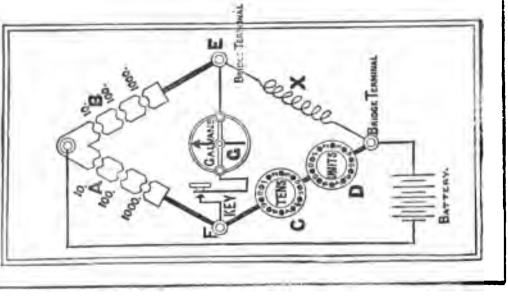


Fig. 149.—Diagram of the "bridge."

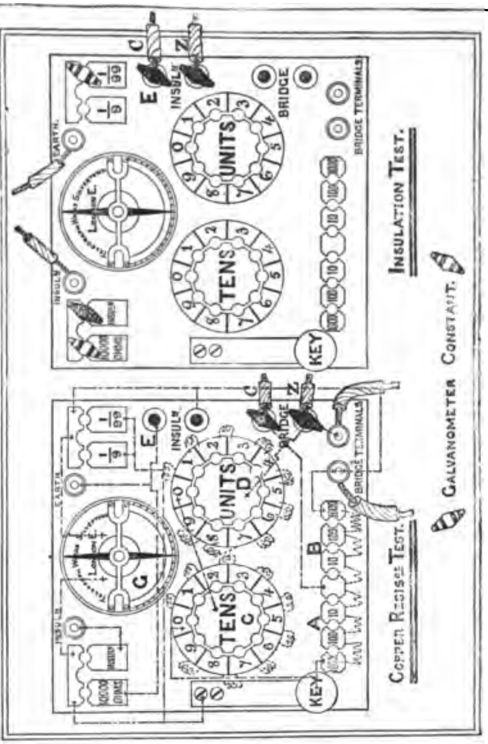


Fig. 150. "Bridge" testing box. Fig. 151.

to each other. Taking the case of obtaining equilibriums with equal resistances: Make the resistance of the ratio sides A B equal by unplugging the 10, 100, or 1000-coil in each; it will be obvious that a balance or state of equilibrium between the points E and F will be obtained when C D = X (X being the wire under measurement); it is therefore necessary to vary C D until no deflection of the galvanometer needle is produced on repeated pressing of the galvanometer key, when C D = X. The testing-box must be placed on a level table, with the galvanometer needle pointing to zero.

It will be observed that by employing equal ratio coils, any resistance between 1 and 99 ohms may be measured; but by a suitable arrangement of ratio resistances, the range can be extended from ·01 ohm to 9,900 ohms, for if the 10 coil in the ratio ann. B, and the 100 coil in the ratio ann. A, are unplugged, a balance will be obtained when the resistance in C D is ten times that of X; therefore C D, divided by 10, will give the resistance of X.

Fig. 150 represents the arrangements of the conductors to the testing-box for taking copper conductor resistance. C Z are the battery terminals. The wire to be tested is inserted in the bridge terminals.

Again, we may have 10 coil in B unplugged, and the 1000 coil in A, in which case we divide the resistance in C D (when a balance is obtained) by 100 to obtain the resistance of X. High resistances are measured in the same manner (always in ohms), but the resistance in ratio ann. B is made higher than that in A. For example, if we make B 100 and A 10, we multiply C D by 10 to obtain X; and if B is 1000, we multiply C D by 100. In the testing box the ratios are placed in front of the ebonite box, the left hand 1000, 100, and 10 coils representing A (see diagram, Fig. 149), and the right hand coils representing B.

Insulation Resistance Tests.—In measuring the insulation resistance of a set of circuits, the first step is to take a constant, which is done on the testing box as follows: Connect the terminals of the battery (use all the cells) to the plug holes marked "Insulation," as shown in Fig. 151. Plug up the 10,000, $\frac{1}{9}$ and $\frac{1}{99}$ shunt, in order to obtain a suitable deflection of the galvanometer needle; call this deflection θ, and the shunt used S.

In taking the test, connect the terminal marked "Earth" to any convenient ground contact, such as a water pipe, and that marked "Insulation" to the conductor or circuit to be tested. The other extremity of this wire is supposed to be insulated. In the case of electric light installations, the earth is frequently represented by other circuits of the same system. In this way leakage from one circuit to another can be detected. Plug up the "Insulation" switch (removing the plug from 10,000), and, if required, $\frac{1}{9}$ or $\frac{1}{99}$ shunt, reproducing as nearly as possible the constant deflection θ.

Let D be the deflection of the galvanometer, and S the shunt, then—

$$\text{Insulation Resistance in ohms} = \frac{\theta \times S \times 10{,}000}{D \times S} \quad (1)$$

If no shunt has been used in the insulation test—

$$\text{Resistance in ohms} = \frac{\theta \times S \times 10{,}000}{D}$$

The multiplying power of the $\frac{1}{9}$ shunt is 10, and that of the $\frac{1}{99}$ shunt 100.

Example.—Suppose the deflection θ when taking the constant to be 45°, the shunt being $\frac{1}{99}$, and the deflection D 20° with $\frac{1}{9}$ shunt, then according to equation 1 :

$$\frac{45 \times 100 \times 10{,}000}{20 \times 10} = 225{,}000 \text{ ohms.}$$

Another example.—The constant deflection being as above, let the deflection $D = 5°$, no shunt being used :

$$\frac{45 \times 100 \times 10{,}000}{5} = 9{,}000{,}000 \text{ ohms or 9 meg ohms.*}$$

When a building is wired, tests of the resistance of the conductors should be taken. The results should approximate closely to the calculated ohms of the different circuits. Tests taken with all the lamps switched on should approximate to the diminished ohms due to the added lamps. The resistances of lamps are rarely constant for a given candle power, but the equation

$$\text{Resistance} = \frac{\text{Ohms of a single lamp, cold}}{\text{Number of lamps in parallel}}$$

will facilitate calculation. Faulty connections or weak points in the circuit are easily detected by the resistance measurement test.

It may be pointed out that the resistance of an incandescent lamp is diminished by heat, hence the *working* resistance is that due to the lamp when fully incandesced. It facilitates calculations to remember

---

* Meg ohm, one million ohms.

that, while heat diminishes the resistance of carbon, it increases that of metal; in arriving at working resistances this point should not be lost sight of, since circuit wires, unless of large section in proportion to the current, become warm under its influence. In measuring the resistance of a lamp cold, only one or two cells of the battery should be used, otherwise the current set up will warm the filament and the reading will be false. Taking resistances of lamps when incandescent is effected by inserting a resistance of, say, 50 ohms in circuit with the lamp (call this resistance R_1), taking a deflection on a high resistance reflecting galvanometer connected to the terminals of the lamp (call this deflection d_1.) Take a deflection (d_2) with the galvanometer connected to the ends of the artificial resistance, then

$$\text{Resistance of lamp, hot} = R_1 \frac{d_1}{d_2}$$

It is scarcely necessary to remind the reader that, prior to taking the resistance of a set of leads and returns, all the lamps must be taken off and the farthest extremities temporarily connected, forming a complete loop. In the case of ship wiring, where only one wire is employed, its extremity would be connected to the shell of the vessel.

Insulation Resistance of the Circuits.—The importance of the insulation testing is daily becoming greater. It is a point to which the attention of fire insurance offices has been particularly directed. Aboard ship the insulation tests are imperative.

Each circuit should be measured according to the method already explained. Different offices have insisted upon different figures, but those required by the Phœnix Fire Office (1888) will answer our present purpose. They are as follow:—

"In any electric light installation in which the current is continuous and has an electro-motive force of 200 volts or under, the insulation resistance *over the whole installation* should not be below the following:—

Installations of	25 lights	500,000 ohms.
,,	50 ,,	250,000 ,,
,,	100 ,,	125,000 ,,
,,	500 ,,	25,000 ,,
,,	1000 ,,	12,500 ,,

. . . . . . for alternate currents the minimum insulation resistance should be twice the above number of ohms." It will be observed that the whole of the circuits are to be grouped in making the test. If each circuit is to be taken separately, the figures will necessarily be much higher.

M. Picou's Rule for Insulation Testing.—This famous rule was communicated to the International Society of Electricians, Paris, November, 1888.

Let R = total insulation resistance of the circuit in ohms.

k, a constant (500) found by experiments with short lengths of wire covered with three layers of cotton wound in reverse directions, and passed between metal plates (representing earth).

E, maximum E. M. F. of the dynamo in volts.

C, total current passing through the circuits in ampères.

Then $$R = k\frac{E}{C}$$

Professor Jamieson's Rule.[*]—The main difference between this rule and that formulated by M. Picou,

---

[*] See a paper by Prof. Jamieson, read before the Institute of Electrical Engineers, Jan. 24, 1889.

lies in the substitution by Professor Jamieson of "lamps" for ampères. It is

$$R_I = k\frac{E}{N_L}$$

where R_I is the total insulation resistance of circuits and generator, or any part thereof, and N_L the number of lamps (of 16 c. p.) in each circuit or in the whole circuit.

The Test for Conductivity or Continuity.

This is the most common as well as the most essential test of an electric light circuit. It is generally conducted by the wiresman himself, by the aid of the simplest apparatus. All that is required consists of a simple galvanometer (a lineman's "detector" is commonly employed), and any source of electricity capable of giving a current of an ampère. Leclanché portable cells are generally employed for this purpose. The circuit to be tested has all its lamps switched off, and the free ends clamped together. The galvanometer and battery are then connected in series across the switch-board terminals of the wires. If a deflection of the needle should not occur as soon as the circuit is closed, it is obvious that there is a total break of continuity in the wires, switches, or cut-outs. If the deflection is but weak, it may imply a faulty joint or some highly resisting point in the circuit. This test is so simple that nothing further need be said respecting it.

Simple Insulation Test.

Fig. 152 represents the arrangement of connections for this test. A wire is taken from a water-pipe, or other good "earth." As strong a battery as convenient (20 Leclanché cells at least should be employed) is connected in series, and through the galvanometer *g* to the lead to be tested. This wire is supposed to be freed from lamps. Its far extremity is insulated. If there is no sign of deflection of the galvanometer on closing the circuit, there is reason to believe that the lead is insulated and secure against leakage to earth. The test should be repeated with the return wires. But this test is not quite satisfactory as ordinarily carried out. The battery power is seldom sufficient. A test taken with a potential difference much lower than that of the dynamo gives no guarantee that the insulation will not fail when the working current is on. The test should obviously be made with a tension above that of the dynamo. This is not easily accomplished, except by means of a pretty large battery of cells, or a miniature dynamo. But it is found that if the test be taken, under ordinary conditions, before the installation is worked and repeated after it has been running for several hours, incipient faults are more apt to

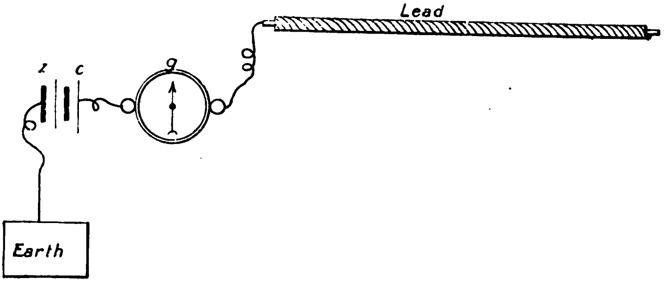


Fig. 152.—The Insulation Test.

be detected. The best kind of tests are those taken with the full current from the dynamo, as explained farther on.

Simple Test for Leakage between Leads and Returns.

The apparatus is arranged as in Fig. 153. As great a battery power as can be procured should be used. The leading and return wires are freed from lamps, which, however, should be in position, and merely switched off. All switches and fuses should be in place. The far extremities of the wires should be insulated as represented. Any deflection of the galvanometer on repeated tapping with the circuit closing key will show that there is leakage between leads and returns. A full deflection will indicate a cross or short-circuit. A weak swing of the needle may show that there is merely a little leakage between the wires at some point where the installation is faulty. As in the case of the earth-test given above, this is only to be regarded as a wiresman's test, and is not always satisfactory.

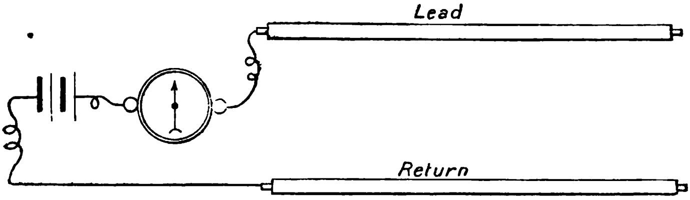


Fig. 153.—Test for Leakage.

The foregoing tests are applicable while the installation is yet incomplete. When all the circuits have been fixed, and the dynamo may be put upon them, both the volt and ampère meters may be utilised to give more reliable and comprehensive information as to the quality of the work.

Test for Working Resistance.

The connections are arranged as in Fig. 154, with an ampère meter in *circuit* and a volt meter across the wires, as represented. All the lamps should be switched in, and the E. M. F. and current raised to their highest values. This affords a ready means of arriving at the resistance by Ohm's law. Call the volts E, the ampères C, and resistance R,

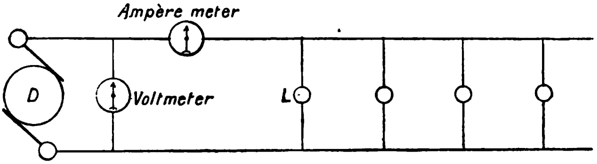


Fig. 154.—Working Resistance Test.

$$\frac{E}{C} = R$$

Lamp Test for Earth Leakage.

When the actual loss by earth leakage is not required to be known in figures the following test, which is very sensitive, may be employed. Fig. 155 represents a dynamo, D, working lamps in parallel. Two lamps of the voltage usually employed are taken for the test. A pair of lamps that have been found on trial to burn *equally bright* when placed simply across the leads, will be found the most suitable. The test lamps are connected as shown, *in series*, across the leads. Both lamps will be found to burn dimly. An earth connection, E, is now taken. When contact is established at a point midway between the test lamps one of the latter will be found to burn *brighter* than the other if there should be any earth leakage. The leakage will be upon the lead to which that lamp is connected, *e.g.* if the left-hand lamp be the brighter, the leak is due to the low lead. The superior brightness of the lamp affords a good deal of information.

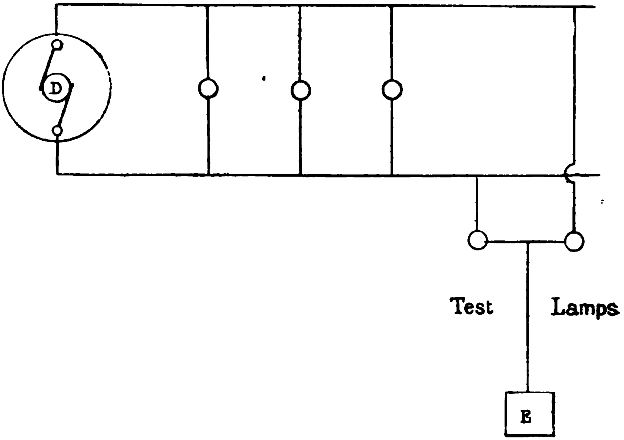


Fig. 155.—Lamp Test for Leakage.

It first proves that there is a current passing to earth, that there is a leak; secondly, it shows upon which wire the leak exists; and thirdly, it gives a fair indication of the extent of the leak by the extent of brightness exhibited over its companion lamp. If the installation be running 100-volt lamps, and the test lamp shows full brilliancy, it may be inferred that the leakage bears some close relationship to the difference of brightness in the two lamps.

Voltmeter Test for Earth Leakage.

Maintaining the installation as in Fig. 154, but with the difference of connecting the voltmeter between one of the leads and a good earth contact, E (Fig. 156), it is advisable to know the resistance of the voltmeter. This by Ohm's law

$$\frac{E}{R} = C$$

affords a ready means of determining the loss by leakage. It is advisable to note the current, C, shown by the ampère meter, and that *c* due to leakage, then

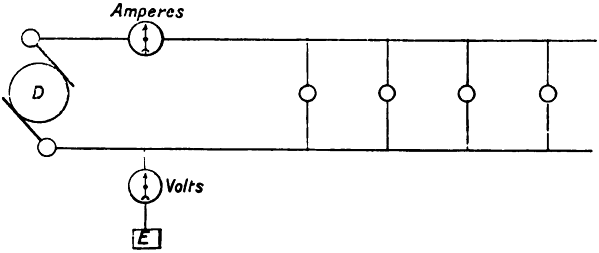


Fig. 156.—Voltmeter Test for Leakage.

$$\frac{C}{c} = k$$

where *k* is the constant representing the insulation resistance. The value should be rather greater than the constant to afford a margin of safety.

Voltmeter Test for Leakage between Leads and Returns.

Switch off (o. s.) all the lamps, and insert the voltmeter first in the circuit of the lower lead, then in the upper lead, as represented in Fig. 157. A very slight leakage can be detected upon running the dynamo at normal speed.

Rough Insulation Test for Dynamo.—This test appears to be applicable only to series machines. The free end of a wire inserted into either terminal of the dynamo is stroked over the ironwork of the machine. When the insulation is defective sparks will appear.

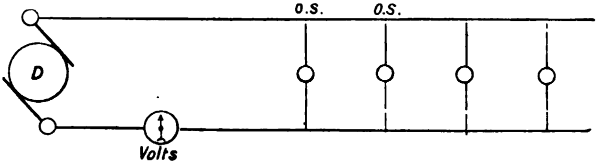


Fig. 157.—Voltmeter Test for Leakage between Leads.

It is questionable whether this test is of any utility unless it be shown that the dynamo is giving circuit.

Insulation of Arc Lighting Circuits.

While the running of leads for arc lighting *outdoors* demands a good deal of careful attention in respect to insulation, this aspect of the subject is invested with considerably greater importance in the case of *indoor* work. In most systems of arc lighting it is only an economical source of illumination when the lamps are put in series upon the circuit. Hence, as the E. M. F. is in proportion to the *number* of lamps, it is common to employ from 500 to 1,000 volts upon such wires. Therefore the danger of short circuits, with their attendant evil consequences, is immensely increased in the case of arc series lighting. There is but one certain course to follow: to run well-covered cables, and to doubly insulate these by lining them upon porcelain fluid insulators. An excellent cup form of the latter is now being used, in which a little resin oil is placed in the annular cup, forming insulation resistance of a very high order. It need scarcely be pointed out that no arc light leads should be concealed. They should be freely exposed to view, lined at a distance several inches from any wall or metallic work. The space between leads and returns indoors should never be less than several inches.

Notes on Conductor Jointing.

The foregoing tests of continuity, resistance and insulation can scarcely be regarded as complete without some reference to the practical work of connecting and jointing conductors.

The Importance of Perfect Jointing.—A joint in an insulated cable or wire is a twofold operation requiring much practice. It implies, first, a perfect *conductive* joint, mechanically as strong as the uncut cable or wire, and, secondly, a perfect *insulation* joint, that can be depended upon to withstand damp or other contingency with at least as great certainty as the uncut insulation of the conductor. The most usual joints are known as parallel and T-joints. The latter is chiefly employed for feeders or branches to lamps.

Parallel Conductor and Insulation Joint.—The details will depend upon the nature of the insulation, but an ordinary leading cable is jointed as follows :—*Metal joint:* Strip off the insulation braiding, tape and indiarubber as carefully as possible, by unwinding for about four inches from each extremity. The insulation is not to be cut off, but must be kept for future wrapping. The cable being stranded, cut out the central wire from each end. Proceed to twist the ends of one cable to those of the other. By careful manipulation each pair of wires may be firmly twisted together. Finally, give the whole a twist, to consolidate the joint. Sprinkle with powdered resin and run soft solder through it with a hot copper bit. It may be remarked that tinning fluid is generally preferred to resin, but it must be used very sparingly upon such a joint. *Insulation joint:* Carefully lap the joint with the unwound cotton, and fix with a coat of insulating varnish. Replace the rubber insulation, and support it outside by a wrapping of indiarubber strip, applied hot and smoothly tooled down. Over all place one or two coatings of felt tape, fixed with varnish.

If the conductor be a *wire*, it is to be scarfed with a file, the two switches forming a splice, which is soldered together and wrapped with fine tinned copper wire and again soldered. The insulating joint is the same. By the exercise of care, and the use of varnish and heat, the insulation joint can be made as good as any other part of the covering.

T-joint.—Cut the insulation through at the junction point in the parallel lead. Unwind the coverings as before, leaving a space of two inches. Bring the bare end of the junction wire across the lead at right angles, to the extreme left of the clearance. Wind the free end of the wire in a tight right-hand spiral around the naked lead, making a number of complete turns. Solder securely. Make the insulation joint as before, using indiarubber strip, and heat to cement all together. Every insulation joint made in rubber-covered wires or cables should withstand immersion in water without exhibiting leakage.

INDEX.

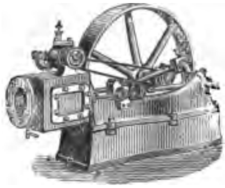
PRINTED BY J. S. VIRTUE AND CO., LIMITED, CITY ROAD, LONDON.

E. S. HINDLEY, Engineer.

London Show Rooms and Stores:

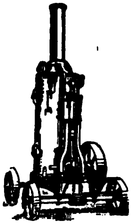
11, QUEEN VICTORIA STREET, E.C.

Works: BOURTON, DORSET.



ECONOMICAL TO USE.

MODERATE IN PRICE.



STEAM ENGINES, Horizontal, Vertical, Portable, or Fixed.

These Engines are controlled by Mr. Hindley's new Governor, which maintains a perfectly uniform speed under sudden variations of work, and is adjustable when working, rendering them especially suitable for Electric Lighting purposes.

Saw Benches, Steam Pumps, Donkey Pumps.

Shafting, Pulleys, &c.

Catalogues, Estimates, and Full Information free on application.

BOOKS FOR

ELECTRICIANS, ELECTRO-METALLURGISTS, &c.

NEW POCKET-BOOK FOR ELECTRICAL ENGINEERS.
Just Published, Royal 32mo, oblong, price 5s. leather.

THE ELECTRICAL ENGINEER'S POCKET-BOOK OF MODERN RULES, FORMULÆ, TABLES, AND DATA. By H. R. KEMPE, M.Inst.E.E., A.M.Inst.C.E., Technical Officer, Postal Telegraphs.

SUMMARY OF CONTENTS:—(1) Weights and Measures; (2) Units; (3) Temperature; (4) Electro-Chemistry, Primary Batteries, and Accumulators; (5) Electro-Metallurgy; (6) Current; (7) Resistances; (8) Capacity; (9) Galvanometers; (10) Fault Testing; (11) Wire; (12) Insulated Wire; (13) Electric Light Leads; (14) Electric Light, Dynamos, and Motors; (15) Rules and Regulations; (16) Telegraph Apparatus; (17) Telephones; (18) Miscellaneous; (19) Mathematical Tables (20) Foreign Money; (21) Dictionary of Technical Terms.

THE ELEMENTARY PRINCIPLES OF ELECTRIC LIGHTING. By ALAN A. CAMPBELL SWINTON, Associate I.E.E. Second Edition, Enlarged and Revised. With 16 Illustrations. Crown 8vo, 1s. 6d. cloth.

ELECTRO-DEPOSITION: A Practical Treatise on the Electrolysis of Gold, Silver, Copper, Nickel, and other Metals and Alloys. By ALEXANDER WATT. Third Edition, Revised and Enlarged. Crown 8vo, 9s. cloth.

"Evidently written by a practical man . . . The information given respecting the details of workshop manipulation is remarkably complete."—*Nature.*

ELECTRO-METALLURGY: Practically Treated. By ALEXANDER WATT, F.R.S.S.A. Ninth Edition, Revised, with Additional Matter and Illustrations, including the most recent Processes. 12mo, 3s. 6d. cloth boards.

CROSBY LOCKWOOD & SON, 7, Stationers' Hall Court, London, E.C.

7, Stationers' Hall Court, London, E.C.
March, 1891.

A
CATALOGUE OF BOOKS

INCLUDING NEW AND STANDARD WORKS IN
ENGINEERING: CIVIL, MECHANICAL, AND MARINE,
MINING AND METALLURGY,
ELECTRICITY AND ELECTRICAL ENGINEERING,
ARCHITECTURE AND BUILDING,
INDUSTRIAL AND DECORATIVE ARTS, SCIENCE, TRADE,
AGRICULTURE, GARDENING,
LAND AND ESTATE MANAGEMENT, LAW, &c.

PUBLISHED BY

CROSBY LOCKWOOD & SON.

MECHANICAL ENGINEERING, etc.

New Manual for Practical Engineers.

THE PRACTICAL ENGINEER'S HAND-BOOK. Comprising a Treatise on Modern Engines and Boilers: Marine, Locomotive and Stationary. And containing a large collection of Rules and Practical Data relating to recent Practice in Designing and Constructing all kinds of Engines, Boilers, and other Engineering work. The whole constituting a comprehensive Key to the Board of Trade and other Examinations for Certificates of Competency in Modern Mechanical Engineering. By Walter S. Hutton, Civil and Mechanical Engineer, Author of "The Works' Manager's Handbook for Engineers," &c. With upwards of 370 Illustrations. Third Edition, Revised, with Additions. Medium 8vo, nearly 500 pp., price 18*s*. Strongly bound.

☞ *This work is designed as a companion to the Author's* "Works' Manager's Hand-book." *It possesses many new and original features, and contains, like its predecessor, a quantity of matter not originally intended for publication, but collected by the author for his own use in the construction of a great variety of modern engineering work.*

The information is given in a condensed and concise form, and is illustrated by upwards of 370 *Woodcuts; and comprises a quantity of tabulated matter of great value to all engaged in designing, constructing, or estimating for* Engines, Boilers *and* other Engineering Work.

⁂ Opinions of the Press.

"We have kept it at hand for several weeks, referring to it as occasion arose, and we have not on a single occasion consulted its pages without finding the information of which we were in quest." —*Athenæum.*

"A thoroughly good practical handbook, which no engineer can go through without learning something that will be of service to him."—*Marine Engineer.*

"An excellent book of reference for engineers, and a valuable text-book for students of engineering."—*Scotsman.*

"This valuable manual embodies the results and experience of the leading authorities on mechanical engineering."—*Building News.*

"The author has collected together a surprising quantity of rules and practical data, and has shown much judgment in the selections he has made. . . . There is no doubt that this book is one of the most useful of its kind published, and will be a very popular compendium."—*Engineer.*

"A mass of information, set down in simple language, and in such a form that it can be easily referred to at any time. The matter is uniformly good and well chosen, and is greatly elucidated by the illustrations. The book will find its way on to most engineers' shelves, where it will rank as one of the most useful books of reference."—*Practical Engineer.*

"Full of useful information, and should be found on the office shelf of a practical engineers." —*English Mechanic.*

Handbook for Works' Managers.

THE WORKS' MANAGER'S HANDBOOK OF MODERN RULES, TABLES, AND DATA. For Engineers, Millwrights, and Boiler Makers; Tool Makers, Machinists, and Metal Workers; Iron and Brass Founders, &c. By W. S. HUTTON, Civil and Mechanical Engineer, Author of "The Practical Engineer's Handbook." Fourth Edition, carefully Revised, and partly Re-written. In One handsome Volume, medium 8vo, price 15*s.* strongly bound. [*Just published.*

☞ *The Author having compiled Rules and Data for his own use in a great variety of modern engineering work, and having found his notes extremely useful, decided to publish them—revised to date—believing that a practical work, suited to the* DAILY REQUIREMENTS OF MODERN ENGINEERS, *would be favourably received.*

In the Third Edition, the following among other additions have been made, viz.: Rules for the Proportions of Riveted Joints in Soft Steel Plates, the Results of Experiments by PROFESSOR KENNEDY *for the Institution of Mechanical Engineers—Rules for the Proportions of Turbines—Rules for the Strength of Hollow Shafts of Whitworth's Compressed Steel, &c.*

⁂ OPINIONS OF THE PRESS.

"The author treats every subject from the point of view of one who has collected workshop notes for application in workshop practice, rather than from the theoretical or literary aspect. The volume contains a great deal of that kind of information which is gained only by practical experience, and is seldom written in books."—*Engineer.*

"The volume is an exceedingly useful one, brimful with engineers' notes, memoranda, and rules, and well worthy of being on every mechanical engineer's bookshelf."—*Mechanical World.*

"The information is precisely that likely to be required in practice. . . . The work forms a desirable addition to the library not only of the works manager, but of anyone connected with general engineering."—*Mining Journal.*

"A formidable mass of facts and figures, readily accessible through an elaborate index . . . . Such a volume will be found absolutely necessary as a book of reference in all sorts of 'works' connected with the metal trades."—*Ryland's Iron Trades Circular.*

"Brimful of useful information, stated in a concise form, Mr. Hutton's books have met a pressing want among engineers. The book must prove extremely useful to every practical man possessing a copy."—*Practical Engineer.*

Practical Treatise on Modern Steam-Boilers.

STEAM-BOILER CONSTRUCTION. A Practical Handbook for Engineers, Boiler-Makers, and Steam Users. Containing a large Collection of Rules and Data relating to the Design, Construction, and Working of Modern Stationary, Locomotive, and Marine Steam-Boilers. By WALTER S. HUTTON, Civil and Mechanical Engineer, Author of "The Works' Manager's Handbook," "The Practical Engineer's Handbook," &c. With upwards of 300 Illustrations.

☞ *This work is written in the same style as Mr. Hutton's other practical Handbooks, which it is intended to supplement. It is in active preparation and will it is expected, be ready in April.*

"The Modernised Templeton."

THE PRACTICAL MECHANIC'S WORKSHOP COMPANION. Comprising a great variety of the most useful Rules and Formulæ in Mechanical Science, with numerous Tables of Practical Data and Calculated Results for Facilitating Mechanical Operations. By WILLIAM TEMPLETON, Author of "The Engineer's Practical Assistant," &c. &c. Sixteenth Edition, Revised, Modernised, and considerably Enlarged by WALTER S. HUTTON, C.E., Author of "The Works' Manager's Handbook," "The Practical Engineer's Handbook," &c. Fcap. 8vo, nearly 500 pp., with Eight Plates and upwards of 250 Illustrative Diagrams, 6*s.*, strongly bound for workshop or pocket wear and tear. [*Just published.*

⁂ OPINIONS OF THE PRESS.

"In its modernised form Hutton's 'Templeton' should have a wide sale, for it contains much valuable information which the mechanic will often find of use, and not a few tables and notes which he might look for in vain in other works. This modernised edition will be appreciated by all who have learned to value the original editions of 'Templeton.'"—*English Mechanic.*

"It has met with great success in the engineering workshop, as we can testify; and there are a great many men who, in a great measure, owe their rise in life to this little book."—*Building News.*

"This familiar text-book—well known to all mechanics and engineers—is of essential service to the every-day requirements of engineers, millwrights, and the various trades connected with engineering and building. The new modernised edition is worth its weight in gold."—*Building News.* (Second Notice.)

"This well-known and largely used book contains information, brought up to date, of the sort so useful to the foreman and draughtsman. So much fresh information has been introduced as to constitute it practically a new book. It will be largely used in the office and workshop."—*Mechanical World.*

"The publishers wisely entrusted the task of revision of this popular, valuable and useful book to Mr. Hutton, than whom a more competent man they could not have found."—*Iron.*

Stone-working Machinery.

STONE-WORKING MACHINERY, and the Rapid and Economical Conversion of Stone. With Hints on the Arrangement and Management of Stone Works. By M. POWIS BALE, M.I.M.E. With Illusts. Crown 8vo, 9s.

"The book should be in the hands of every mason or student of stone-work."—*Colliery Guardian.*

"It is in every sense of the word a standard work upon a subject which the author is fully competent to deal exhaustively with."—*Builder's Weekly Reporter.*

"A capital handbook for all who manipulate stone for building or ornamental purposes."—*Machinery Market.*

Pump Construction and Management.

PUMPS AND PUMPING: A Handbook for Pump Users. Being Notes on Selection, Construction and Management. By M. POWIS BALE, M.I.M.E., Author of "Woodworking Machinery," "Saw Mills," &c. Crown 8vo, 2s. 6d. cloth. [*Just published.*

"The matter is set forth as concisely as possible. In fact, condensation rather than diffuseness has been the author's aim throughout; yet he does not seem to have omitted anything likely to be of use."—*Journal of Gas Lighting.*

"Thoroughly practical and simply and clearly written."—*Glasgow Herald.*

Turning.

LATHE-WORK: A Practical Treatise on the Tools, Appliances, and Processes employed in the Art of Turning. By PAUL N. HASLUCK. Fourth Edition, Revised and Enlarged. Cr. 8vo, 5s. cloth. [*Just published.*

"Written by a man who knows, not only how work ought to be done, but who also knows how to do it, and how to convey his knowledge to others. To all turners this book would be valuable."—*Engineering.*

"We can safely recommend the work to young engineers. To the amateur it will simply be nvaluable. To the student it will convey a great deal of useful information."—*Engineer.*

"A compact, succinct, and handy guide to lathe-work did not exist in our language until Mr. Hasluck, by the publication of this treatise, gave the turner a true *vade-mecum.*"—*House Decorator*

Screw-Cutting.

SCREW THREADS: And Methods of Producing Them. With Numerous Tables, and complete directions for using Screw-Cutting Lathes. By PAUL N. HASLUCK, Author of "Lathe-Work," &c. With Fifty Illustrations. Third Edition, Revised and Enlarged. Waistcoat-pocket size, 1s. 6d. cloth. [*Just published.*

"Full of useful information, hints and practical criticism. Taps, dies and screwing-tools generally are illustrated and their action described."—*Mechanical World.*

"It is a complete compendium of all the details of the screw cutting lathe; in fact a *multum-in-parvo* on all the subjects it treats upon."—*Carpenter and Builder.*

Smith's Tables for Mechanics, etc.

TABLES, MEMORANDA, AND CALCULATED RESULTS, FOR MECHANICS, ENGINEERS, ARCHITECTS, BUILDERS, etc. Selected and Arranged by FRANCIS SMITH. Fifth Edition, thoroughly Revised and Enlarged, with a New Section of ELECTRICAL TABLES, FORMULÆ, and MEMORANDA. Waistcoat-pocket size, 1s. 6d. limp leather. [*Just published.*

"It would, perhaps, be as difficult to make a small pocket-book selection of notes and formulæ to suit ALL engineers as it would be to make a universal medicine; but Mr. Smith's waistcoat-pocket collection may be looked upon as a successful attempt."—*Engineer.*

"The best example we have ever seen of 250 pages of useful matter packed into the dimensions of a card-case."—*Building News.* "A veritable pocket treasury of knowledge."—*Iron.*

Engineer's and Machinist's Assistant.

THE ENGINEER'S, MILLWRIGHT'S, and MACHINIST'S PRACTICAL ASSISTANT. A collection of Useful Tables, Rules and Data. By WILLIAM TEMPLETON. 7th Edition, with Additions. 18mo, 2s. 6d. cloth.

"Occupies a foremost place among books of this kind. A more suitable present to an apprentice to any of the mechanical trades could not possibly be made."—*Building News.*

"A deservedly popular work, it should be in the 'drawer' of every mechanic."—*English Mechanic.*

Iron and Steel.

"IRON AND STEEL": A Work for the Forge, Foundry, Factory, and Office. Containing ready, useful, and trustworthy Information for Ironmasters and their Stock-takers; Managers of Bar, Rail, Plate, and Sheet Rolling Mills; Iron and Metal Founders; Iron Ship and Bridge Builders; Mechanical, Mining, and Consulting Engineers; Architects, Contractors, Builders, and Professional Draughtsmen. By CHARLES HOARE, Author of "The Slide Rule," &c. Eighth Edition, Revised throughout and considerably Enlarged. 32mo, 6s. leather.

"For comprehensiveness the book has not its equal."—*Iron.*

"One of the best of the pocket books."—*English Mechanic.*

"We cordially recommend this book to those engaged in considering the details of all kinds of iron and steel works."—*Naval Science.*

Engineering Construction.

PATTERN-MAKING: A Practical Treatise, embracing the Main Types of Engineering Construction, and including Gearing, both Hand and Machine made, Engine Work, Sheaves and Pulleys, Pipes and Columns, Screws, Machine Parts, Pumps and Cocks, the Moulding of Patterns in Loam and Greensand, &c., together with the methods of Estimating the weight of Castings; to which is added an Appendix of Tables for Workshop Reference. By a FOREMAN PATTERN MAKER. With upwards of Three Hundred and Seventy Illustrations. Crown 8vo, 7*s*. 6*d*. cloth.

"A well-written technical guide, evidently written by a man who understands and has practised what he has written about. . . . We cordially recommend it to engineering students, young journeymen, and others desirous of being initiated into the mysteries of pattern-making."—*Builder.*

"We can confidently recommend this comprehensive treatise.'—*Building News.*

"Likely to prove a welcome guide to many workmen, especially to draughtsmen who have lacked a training in the shops, pupils pursuing their practical studies in our factories, and to employers and managers in engineering works."—*Hardware Trade Journal.*

"More than 370 illustrations help to explain the text, which is, however, always clear and explicit, thus rendering the work an excellent *vade mecum* for the apprentice who desires to become master of his trade."—*English Mechanic.*

Dictionary of Mechanical Engineering Terms.

LOCKWOOD'S DICTIONARY OF TERMS USED IN THE PRACTICE OF MECHANICAL ENGINEERING, embracing those current in the Drawing Office, Pattern Shop, Foundry, Fitting, Turning, Smith's and Boiler Shops, &c. &c. Comprising upwards of 6,000 Definitions. Edited by A FOREMAN PATTERN-MAKER, Author of "Pattern Making." Crown 8vo, 7*s*. 6*d*. cloth.

"Just the sort of handy dictionary required by the various trades engaged in mechanical engineering. The practical engineering pupil will find the book of great value in his studies, and every foreman engineer and mechanic should have a copy."—*Building News.*

"After a careful examination of the book, and trying all manner of words, we think that the engineer will here find all he is likely to require. It will be largely used."—*Practical Engineer.*

"One of the most useful books which can be presented to a mechanic or student."—*English Mechanic.*

"Not merely a dictionary, but, to a certain extent, also a most valuable guide. It strikes us as a happy idea to combine with a definition of the phrase useful information on the subject of which it treats."—*Machinery Market.*

"No word having connection with any branch of constructive engineering seems to be omitted. No more comprehensive work has been, so far, issued."—*Knowledge.*

"We strongly commend this useful and reliable adviser to our friends in the workshop, and to students everywhere."—*Colliery Guardian.*

Steam Boilers.

A TREATISE ON STEAM BOILERS: Their Strength, Construction, and Economical Working. By ROBERT WILSON, C.E. Fifth Edition. 12mo, 6*s*. cloth.

"The best treatise that has ever been published on steam boilers."—*Engineer.*

"The author shows himself perfect master of his subject, and we heartily recommend all employing steam power to possess themselves of the work."—*Ryland's Iron Trade Circular.*

Boiler Chimneys.

BOILER AND FACTORY CHIMNEYS; Their Draught-Power and Stability. With a Chapter on *Lightning Conductors.* By ROBERT WILSON, A.I.C.E., Author of "A Treatise on Steam Boilers," &c. Second Edition. Crown 8vo, 3*s*. 6*d*. cloth.

"Full of useful information, definite in statement, and thoroughly practical in treatment. —*The Local Government Chronicle.*

"A valuable contribution to the literature of scientific building."—*The Builder.*

Boiler Making.

THE BOILER-MAKER'S READY RECKONER & ASSISTANT. With Examples of Practical Geometry and Templating, for the Use of Platers, Smiths and Riveters. By JOHN COURTNEY, Edited by D. K. CLARK, M.I.C.E. Third Edition, 480 pp., with 140 Illusts. Fcap. 8vo, 7*s*. half-bound.

"A most useful work. . . . No workman or apprentice should be without this book."—*Iron Trade Circular.*

"Boiler-makers will readily recognise the value of this volume. . . . The tables are clearly printed, and so arranged that they can be referred to with the greatest facility, so that it cannot be doubted that they will be generally appreciated and much used."—*Mining Journal.*

Warming.

HEATING BY HOT WATER; with Information and Suggestions on the best Methods of Heating Public, Private and Horticultural Buildings. By WALTER JONES. With upwards of 50 Illustrations, crown 8vo, 2*s*. cloth.

"We confidently recommend all interested in heating by hot water to secure a copy of this valuable little treatise."—*The Plumber and Decorator.*

Steam Engine.

TEXT-BOOK ON THE STEAM ENGINE. With a Supplement on Gas Engines, and PART II. ON HEAT ENGINES. By T. M. GOODEVE, M.A., Barrister-at-Law, Professor of Mechanics at the Normal School of Science and the Royal School of Mines; Author of "The Principles of Mechanics," "The Elements of Mechanism," &c. Eleventh Edition, Enlarged. With numerous Illustrations. Crown 8vo, 6*s.* cloth. [*Just published.*

"Professor Goodeve has given us a treatise on the steam engine which will bear comparison with anything written by Huxley or Maxwell, and we can award it no higher praise."—*Engineer.*

"Mr. Goodeve's text-book is a work of which every young engineer should possess himself.' —*Mining Journal.*

"Essentially practical in its aim. The manner of exposition leaves nothing to be desired."—*Scotsman.*

Gas Engines.

ON GAS-ENGINES. Being a Reprint, with some Additions, of the Supplement to the *Text-book on the Steam Engine,* by T. M. GOODEVE, M.A. Crown 8vo, 2*s.* 6*d.* cloth.

"Like all Mr. Goodeve's writings, the present is no exception in point of general excellence It is a valuable little volume."—*Mechanical World.*

Steam.

THE SAFE USE OF STEAM. Containing Rules for Unprofessional Steam-users. By an ENGINEER. Sixth Edition. Sewed, 6*d.*

"If steam-users would but learn this little book by heart boiler explosions would become sensations by their rarity."—*English Mechanic.*

Office Book for Mechanical Engineers.

THE MECHANICAL ENGINEER'S REFERENCE BOOK, for Machine and Boiler Construction. In Two Parts. Part I. GENERAL ENGINEERING DATA. Part II. BOILER CONSTRUCTION. With 48 Plates and numerous Illustrations. By NELSON FOLEY, M.I.N.A. Folio, half-bound. Price £5 5*s.* [*Nearly ready.*

Coal and Speed Tables.

A POCKET BOOK OF COAL AND SPEED TABLES, for Engineers and Steam-users. By NELSON FOLEY, Author of "Boiler Construction." Pocket-size, 3*s.* 6*d.* cloth; 4*s.* leather.

"These tables are designed to meet the requirements of every-day use; they are of sufficient scope for most practical purposes, and may be commended to engineers and users of steam."—*Iron.*

"This pocket-book well merits the attention of the practical engineer. Mr. Foley has compiled a very useful set of tables, the information contained in which is frequently required by engineers, coal consumers and users of steam."—*Iron and Coal Trades Review.*

Fire Engineering.

FIRES, FIRE-ENGINES, AND FIRE-BRIGADES. With a History of Fire-Engines, their Construction, Use, and Management; Remarks on Fire-Proof Buildings, and the Preservation of Life from Fire; Statistics of the Fire Appliances in English Towns; Foreign Fire Systems; Hints on Fire Brigades, &c. &c. By CHARLES F. T. YOUNG, C.E. With numerous Illustrations, 544 pp., demy 8vo, £1 4*s.* cloth.

"To such of our readers as are interested in the subject of fires and fire apparatus, we can most heartily commend this book. It is really the only English work we now have upon the subject."—*Engineering.*

"It displays much evidence of careful research; and Mr. Young has put his facts neatly together. It is evident enough that his acquaintance with the practical details of the construction of steam fire engines, old and new, and the conditions with which it is necessary they should comply, is accurate and full."—*Engineer.*

Estimating for Engineering Work, &c.

ENGINEERING ESTIMATES, COSTS AND ACCOUNTS: A Guide to Commercial Engineering. With numerous Examples of Estimates and Costs of Millwright Work, Miscellaneous Productions, Steam Engines and Steam Boilers; and a Section on the Preparation of Costs Accounts. By A GENERAL MANAGER. Demy 8vo, 12*s.* cloth. [*Just published.*

"This is an excellent and very useful book, covering subject-matter in constant requisition in every factory and workshop. . . . The book is invaluable, not only to the young engineer, but also to the estimate department of every works."—*Builder.*

"This book bears on every page evidence that it has been prepared by an engineer accustomed to the work, and is no mere compilation, but contains a mass of valuable information of a kind useful even to experienced engineers."—*Practical Engineer.*

"We accord the work unqualified praise. The information is given in a plain, straightforward manner, and bears throughout evidence of the intimate practical acquaintance of the author with every phrase of commercial engineering."—*Mechanical World.*

THE POPULAR WORKS OF MICHAEL REYNOLDS

("THE ENGINE DRIVER'S FRIEND").

Locomotive-Engine Driving.

LOCOMOTIVE-ENGINE DRIVING: A Practical Manual for Engineers in charge of Locomotive Engines. By MICHAEL REYNOLDS, Member of the Society of Engineers, formerly Locomotive Inspector L. B. and S. C. R. Eighth Edition. Including a KEY TO THE LOCOMOTIVE ENGINE. With Illustrations and Portrait of Author. Crown 8vo, 4*s*. 6*d*. cloth.

"Mr. Reynolds has supplied a want, and has supplied it well. We can confidently recommend the book, not only to the practical driver, but to everyone who takes an interest in the performance of locomotive engines."—*The Engineer.*

"Mr. Reynolds has opened a new chapter in the literature of the day. This admirable practical treatise, of the practical utility of which we have to speak in terms of warm commendation."—*Athenæum.*

"Evidently the work of one who knows his subject thoroughly."—*Railway Service Gazette.*

"Were the cautions and rules given in the book to become part of the every-day working of our engine-drivers, we might have fewer distressing accidents to deplore."—*Scotsman.*

Stationary Engine Driving.

STATIONARY ENGINE DRIVING: A Practical Manual for Engineers in charge of Stationary Engines. By MICHAEL REYNOLDS. Fourth Edition, Enlarged. With Plates and Woodcuts. Crown 8vo, 4*s*. 6*d*. cloth.

"The author is thoroughly acquainted with his subjects, and his advice on the various points treated is clear and practical. . . . He has produced a manual which is an exceedingly useful one for the class for whom it is specially intended."—*Engineering.*

"Our author leaves no stone unturned. He is determined that his readers shall not only know something about the stationary engine, but all about it."—*Engineer.*

"An engineman who has mastered the contents of Mr. Reynolds's book will require but little actual experience with boilers and engines before he can be trusted to look after them."—*English Mechanic.*

The Engineer, Fireman, and Engine-Boy.

THE MODEL LOCOMOTIVE ENGINEER, FIREMAN, and ENGINE-BOY. Comprising a Historical Notice of the Pioneer Locomotive Engines and their Inventors. By MICHAEL REYNOLDS. With numerous Illustrations and a fine Portrait of George Stephenson. Crown 8vo, 4*s*. 6*d*. cloth.

"From the technical knowledge of the author it will appeal to the railway man of to-day more forcibly than anything written by Dr. Smiles. . . . The volume contains information of a technical kind, and facts that every driver should be familiar with."—*English Mechanic.*

"We should be glad to see this book in the possession of everyone in the kingdom who has ever laid, or is to lay, hands on a locomotive engine."—*Iron.*

Continuous Railway Brakes.

CONTINUOUS RAILWAY BRAKES: A Practical Treatise on the several Systems in Use in the United Kingdom; their Construction and Performance. With copious Illustrations and numerous Tables. By MICHAEL REYNOLDS. Large crown 8vo, 9*s*. cloth.

"A popular explanation of the different brakes. It will be of great assistance in forming public opinion, and will be studied with benefit by those who take an interest in the brake."—*English Mechanic.*

"Written with sufficient technical detail to enable the principle and relative connection of the various parts of each particular brake to be readily grasped."—*Mechanical World.*

Engine-Driving Life.

ENGINE-DRIVING LIFE: Stirring Adventures and Incidents in the Lives of Locomotive-Engine Drivers. By MICHAEL REYNOLDS. Second Edition, with Additional Chapters. Crown 8vo, 2*s*. cloth.

"From first to last perfectly fascinating. Wilkie Collins's most thrilling conceptions are thrown into the shade by true incidents, endless in their variety, related in every page."—*North British Mail.*

"Anyone who wishes to get a real insight into railway life cannot do better than read 'Engine-Driving Life' for himself; and if he once take it up he will find that the author's enthusiasm and real love of the engine-driving profession will carry him on till he has read every page."—*Saturday Review.*

Pocket Companion for Enginemen.

THE ENGINEMAN'S POCKET COMPANION AND PRACTICAL EDUCATOR FOR ENGINEMEN, BOILER ATTENDANTS, AND MECHANICS. By MICHAEL REYNOLDS. With Forty-five Illustrations and numerous Diagrams. Second Edition, Revised. Royal 18mo, 3*s*. 6*d*., strongly bound for pocket wear.

"This admirable work is well suited to accomplish its object, being the honest workmanship of a competent engineer."—*Glasgow Herald.*

"A most meritorious work, giving in a succinct and practical form all the information an engine-minder desirous of mastering the scientific principles of his daily calling would require."—*Miller.*

"A boon to those who are striving to become efficient mechanics."—*Daily Chronicle.*

French-English Glossary for Engineers, etc.

A POCKET GLOSSARY of TECHNICAL TERMS: ENGLISH-FRENCH, FRENCH-ENGLISH; with Tables suitable for the Architectural, Engineering, Manufacturing and Nautical Professions. By JOHN JAMES FLETCHER, Engineer and Surveyor. 200 pp. Waistcoat-pocket size, 1s. 6*d*., limp leather.

"It ought certainly to be in the waistcoat-pocket of every professional man."—*Iron.*

"It is a very great advantage for readers and correspondents in France and England to have so large a number of the words relating to engineering and manufacturers collected in a liliputian volume. The little book will be useful both to students and travellers.'—*Architect.*

"The glossary of terms is very complete, and many of the tables are new and well arranged. We cordially commend the book."—*Mechanical World*

Portable Engines.

THE PORTABLE ENGINE; ITS CONSTRUCTION AND MANAGEMENT. A Practical Manual for Owners and Users of Steam Engines generally. By WILLIAM DYSON WANSBROUGH. With 90 Illustrations. Crown 8vo, 3s. 6*d*. cloth.

"This is a work of value to those who use steam machinery. . . . Should be read by everyone who has a steam engine, on a farm or elsewhere."—*Mark Lane Express.*

"We cordially commend this work to buyers and owners of steam engines, and to those who have to do with their construction or use."—*Timber Trades Journal.*

"Such a general knowledge of the steam engine as Mr. Wansbrough furnishes to the reader should be acquired by all intelligent owners and others who use the steam engine."—*Building News.*

"An excellent text-book of this useful form of engine, which describes with all necessary minuteness the details of the various devices. . . 'The Hints to Purchasers contain a good deal of commonsense and practical wisdom."—*English Mechanic.*

CIVIL ENGINEERING, SURVEYING, etc.

MR. HUMBER'S IMPORTANT ENGINEERING BOOKS.

The Water Supply of Cities and Towns.

A COMPREHENSIVE TREATISE on the WATER-SUPPLY OF CITIES AND TOWNS. By WILLIAM HUMBER, A-M.Inst.C.E., and M. Inst. M.E., Author of "Cast and Wrought Iron Bridge Construction," &c. &c. Illustrated with 50 Double Plates, 1 Single Plate, Coloured Frontispiece, and upwards of 250 Woodcuts, and containing 400 pages of Text. Imp. 4to, £6 6s. elegantly and substantially half-bound in morocco.

List of Contents.

I. Historical Sketch of some of the means that have been adopted for the Supply of Water to Cities and Towns.—II. Water and the Foreign Matter usually associated with it.—III. Rainfall and Evaporation.—IV. Springs and the water-bearing formations of various districts.—V. Measurement and Estimation of the flow of Water.—VI. On the Selection of the Source of Supply.—VII. Wells.—VIII. Reservoirs.—IX. The Purification of Water.—X. Pumps.—XI. Pumping Machinery.—XII. Conduits.—XIII. Distribution of Water.—XIV. Meters, Service Pipes, and House Fittings.—XV. The Law and Economy of Water Works. XVI. Constant and Intermittent Supply.—XVII. Description of Plates.—Appendices, giving Tables of Rates of Supply, Velocities, &c. &c., together with Specifications of several Works illustrated, among which will be found: Aberdeen, Bideford, Canterbury, Dundee, Halifax, Lambeth, Rotherham, Dublin, and others.

"The most systematic and valuable work upon water supply hitherto produced in English, or in any other language. . . . Mr. Humber's work is characterised almost throughout by an exhaustiveness much more distinctive of French and German than of English technical treatises." —*Engineer.*

"We can congratulate Mr. Humber on having been able to give so large an amount of information on a subject so important as the water supply of cities and towns. The plates, fifty in number, are mostly drawings of executed works, and alone would have commanded the attention of every engineer whose practice may lie in this branch of the profession."—*Builder.*

Cast and Wrought Iron Bridge Construction.

A COMPLETE AND PRACTICAL TREATISE ON CAST AND WROUGHT IRON BRIDGE CONSTRUCTION, including Iron Foundations. In Three Parts—Theoretical, Practical, and Descriptive. By WILLIAM HUMBER, A.M.Inst.C.E., and M.Inst.M.E. Third Edition, Revised and much improved, with 115 Double Plates (20 of which now first appear in this edition), and numerous Additions to the Text. In Two Vols., imp. 4to, £6 16*s*. 6*d*. half-bound in morocco.

"A very valuable contribution to the standard literature of civil engineering. In addition to elevations, plans and sections, large scale details are given which very much enhance the instructive worth of those illustrations."—*Civil Engineer and Architect's Journal.*

"Mr. Humber's stately volumes, lately issued—in which the most important bridges erected during the last five years, under the direction of the late Mr. Brunel, Sir W. Cubitt, Mr. Hawkshaw, Mr. Page, Mr. Fowler, Mr. Hemans, and others among our most eminent engineers, are drawn and specified in great detail."—*Engineer.*

MR. HUMBER'S GREAT WORK ON MODERN ENGINEERING.

Complete in Four Volumes, imperial 4to, price £12 12s., half-morocco. Each Volume sold separately as follows:—

A RECORD OF THE PROGRESS OF MODERN ENGINEERING. **First Series. Comprising Civil, Mechanical, Marine, Hydraulic, Railway, Bridge, and other Engineering Works, &c. By William Humber, A-M.Inst.C.E., &c. Imp. 4to, with 36 Double Plates, drawn to a large scale, Photographic Portrait of John Hawkshaw, C.E., F.R.S., &c., and copious descriptive Letterpress, Specifications, &c., £3 3s. half-morocco.**

List of the Plates and Diagrams.

Victoria Station and Roof, L. B. & S. C. R. (8 plates); Southport Pier (2 plates); Victoria Station and Roof, L. C. & D. and G. W. R. (6 plates); Roof of Cremorne Music Hall; Bridge over G. N. Railway; Roof of Station, Dutch Rhenish Rail (2 plates); Bridge over the Thames, West London Extension Railway (5 plates); Armour Plates: Suspension Bridge, Thames (4 plates); The Allen Engine; Suspension Bridge, Avon (3 plates); Underground Railway (3 plates).

"Handsomely lithographed and printed. It will find favour with many who desire to preserve in a permanent form copies of the plans and specifications prepared for the guidance of the contractors for many important engineering works."—*Engineer.*

HUMBER'S RECORD OF MODERN ENGINEERING. **Second Series. Imp. 4to, with 36 Double Plates, Photographic Portrait of Robert Stephenson, C.E., M.P., F.R.S., &c., and copious descriptive Letterpress, Specifications, &c., £3 3s. half-morocco.**

List of the Plates and Diagrams.

Birkenhead Docks, Low Water Basin (15 plates); Charing Cross Station Roof, C. C. Railway (3 plates); Digswell Viaduct, Great Northern Railway; Robbery Wood Viaduct, Great Northern Railway; Iron Permanent Way; Clydach Viaduct, Merthyr, Tredegar, and Abergavenny Railway; Ebbw Viaduct, Merthyr, Tredegar, and Abergavenny Railway; College Wood Viaduct, Cornwall Railway; Dublin Winter Palace Roof (3 plates); Bridge over the Thames, L. C. & D. Railway (6 plates); Albert Harbour, Greenock (4 plates).

"Mr. Humber has done the profession good and true service, by the fine collection of examples he has here brought before the profession and the public."—*Practical Mechanic's Journal.*

HUMBER'S RECORD OF MODERN ENGINEERING. **Third Series. Imp. 4to, with 40 Double Plates, Photographic Portrait of J. R. M'Clean, late Pres. Inst. C.E., and copious descriptive Letterpress, Specifications, &c., £3 3s. half-morocco.**

List of the Plates and Diagrams.

Main Drainage, Metropolis.—*North Side.*—Map showing Interception of Sewers; Middle Level Sewer (2 plates); Outfall Sewer, Bridge over River Lea (3 plates); Outfall Sewer, Bridge over Marsh Lane, North Woolwich Railway, and Bow and Barking Railway Junction; Outfall Sewer, Bridge over Bow and Barking Railway (3 plates); Outfall Sewer, Bridge over East London Waterworks' Feeder (2 plates); Outfall Sewer, Reservoir (2 plates); Outfall Sewer, Tumbling Bay and Outlet; Outfall Sewer, Penstocks. *South Side.*—Outfall Sewer, Bermondsey Branch (2 plates); Outfall Sewer, Reservoir and Outlet (4 plates); Outfall Sewer, Filth Hoist; Sections of Sewers (North and South Sides).

Thames Embankment.—Section of River Wall; Steamboat Pier, Westminster (2 plates); Landing Stairs between Charing Cross and Waterloo Bridges; York Gate (2 plates); Overflow and Outlet at Savoy Street Sewer (3 plates); Steamboat Pier, Waterloo Bridge (3 plates); Junction of Sewers, Plans and Sections; Gullies, Plans and Sections; Rolling Stock; Granite and Iron Forts.

"The drawings have a constantly increasing value, and whoever desires to possess clear representations of the two great works carried out by our Metropolitan Board will obtain Mr. Humber's volume."—*Engineer.*

HUMBER'S RECORD OF MODERN ENGINEERING. **Fourth Series. Imp. 4to, with 36 Double Plates, Photographic Portrait of John Fowler, late Pres. Inst. C.E., and copious descriptive Letterpress, Specifications, &c., £3 3s. half-morocco.**

List of the Plates and Diagrams.

Abbey Mills Pumping Station, Main Drainage, Metropolis (4 plates); Barrow Docks (5 plates); Manquis Viaduct, Santiago and Valparaiso Railway (2 plates); Adam's Locomotive, St. Helen's Canal Railway (2 plates); Cannon Street Station Roof, Charing Cross Railway (3 plates); Road Bridge over the River Moka (2 plates); Telegraphic Apparatus for Mesopotamia; Viaduct over the River Wye, Midland Railway (3 plates); St. Germans Viaduct, Cornwall Railway (2 plates); Wrought-Iron Cylinder for Diving Bell; Millwall Docks (6 plates); Milroy's Patent Excavator; Metropolitan District Railway (6 plates); Harbours, Ports, and Breakwaters (3 plates).

"We gladly welcome another year's issue of this valuable publication from the able pen of Mr. Humber. The accuracy and general excellence of this work are well known, while its usefulness in giving the measurements and details of some of the latest examples of engineering, as carried out by the most eminent men in the profession, cannot be too highly prized."—*Artizan.*

MR. HUMBER'S ENGINEERING BOOKS—*continued.*

Strains, Calculation of.

A HANDY BOOK FOR THE CALCULATION OF STRAINS IN GIRDERS AND SIMILAR STRUCTURES, AND THEIR STRENGTH. Consisting of Formulæ and Corresponding Diagrams, with numerous details for Practical Application, &c. By WILLIAM HUMBER, A-M.Inst.C.E., &c. Fourth Edition. Crown 8vo, nearly 100 Woodcuts and 3 Plates, 7*s.* 6*d.* cloth.

"The formulæ are neatly expressed, and the diagrams good."—*Athenæum.*

"We heartily commend this really *handy* book to our engineer and architect readers."—*English Mechanic.*

Barlow's Strength of Materials, enlarged by Humber

A TREATISE ON THE STRENGTH OF MATERIALS; with Rules for Application in Architecture, the Construction of Suspension Bridges, Railways, &c. By PETER BARLOW, F.R.S. A New Edition, revised by his Sons, P. W. BARLOW, F.R.S., and W. H. BARLOW, F.R.S.; to which are added, Experiments by HODGKINSON, FAIRBAIRN, and KIRKALDY; and Formulæ for Calculating Girders, &c. Arranged and Edited by W. HUMBER, A-M.Inst.C.E. Demy 8vo, 400 pp., with 19 large Plates and numerous Woodcuts, 18*s.* cloth.

"Valuable alike to the student, tyro, and the experienced practitioner, it will always rank in future, as it has hitherto done, as the standard treatise on that particular subject."—*Engineer.*

"There is no greater authority than Barlow."—*Building News.*

"As a scientific work of the first class, it deserves a foremost place on the bookshelves of every civil engineer and practical mechanic."—*English Mechanic.*

Trigonometrical Surveying.

AN OUTLINE OF THE METHOD OF CONDUCTING A TRIGONOMETRICAL SURVEY, for the Formation of Geographical and Topographical Maps and Plans, Military Reconnaissance, Levelling, &c., with Useful Problems, Formulæ, and Tables. By Lieut.-General FROME, R.E. Fourth Edition, Revised and partly Re-written by Major General Sir CHARLES WARREN, G.C.M.G., R.E. With 19 Plates and 115 Woodcuts, royal 8vo, 16*s.* cloth.

"The simple fact that a fourth edition has been called for is the best testimony to its merits. No words of praise from us can strengthen the position so well and so steadily maintained by this work. Sir Charles Warren has revised the entire work, and made such additions as were necessary to bring every portion of the contents up to the present date."—*Broad Arrow.*

Field Fortification.

A TREATISE ON FIELD FORTIFICATION, THE ATTACK OF FORTRESSES, MILITARY MINING, AND RECONNOITRING. By Colonel I. S. MACAULAY, late Professor of Fortification in the R.M.A., Woolwich. Sixth Edition, crown 8vo, cloth, with separate Atlas of 12 Plates, 12*s.*

Oblique Bridges.

A PRACTICAL AND THEORETICAL ESSAY ON OBLIQUE BRIDGES. With 13 large Plates. By the late GEORGE WATSON BUCK, M.I.C.E. Third Edition, revised by his Son, J. H. WATSON BUCK, M.I.C.E.; and with the addition of Description to Diagrams for Facilitating the Construction of Oblique Bridges, by W. H. BARLOW, M.I.C.E. Royal 8vo, 12*s.* cloth.

"The standard text-book for all engineers regarding skew arches is Mr. Buck's treatise, and it would be impossible to consult a better."—*Engineer.*

"Mr. Buck's treatise is recognised as a standard text-book, and his treatment has divested the subject of many of the intricacies supposed to belong to it. As a guide to the engineer and architect, on a confessedly difficult subject, Mr. Buck's work is unsurpassed."—*Building News.*

Water Storage, Conveyance and Utilisation.

WATER ENGINEERING: A Practical Treatise on the Measurement, Storage, Conveyance and Utilisation of Water for the Supply of Towns, for Mill Power, and for other Purposes. By CHARLES SLAGG, Water and Drainage Engineer, A.M.Inst.C.E., Author of "Sanitary Work in the Smaller Towns, and in Villages," &c. With numerous Illusts. Cr. 8vo, 7*s.* 6*d.* cloth.

"As a small practical treatise on the water supply of towns, and on some applications of water-power, the work is in many respects excellent."—*Engineering.*

"The author has collated the results deduced from the experiments of the most eminent authorities, and has presented them in a compact and practical form, accompanied by very clear and detailed explanations. . . . The application of water as a motive power is treated very carefully and exhaustively."—*Builder.*

"For anyone who desires to begin the study of hydraulics with a consideration of the practical applications of the science there is no better guide."—*Architect.*

Statics, Graphic and Analytic.

GRAPHIC AND ANALYTIC STATICS, in their Practical Application to the Treatment of Stresses in Roofs, Solid Girders, Lattice, Bowstring and Suspension Bridges, Braced Iron Arches and Piers, and other Frameworks. By R. HUDSON GRAHAM, C.E. Containing Diagrams and Plates to Scale. With numerous Examples, many taken from existing Structures. Specially arranged for Class-work in Colleges and Universities. Second Edition, Revised and Enlarged. 8vo, 16*s.* cloth.

"Mr. Graham's book will find a place wherever graphic and analytic statics are used or studied." —*Engineer.*

"The work is excellent from a practical point of view, and has evidently been prepared with much care. The directions for working are ample, and are illustrated by an abundance of well-selected examples. It is an excellent text-book for the practical draughtsman."—*Athenæum.*

Student's Text-Book on Surveying.

PRACTICAL SURVEYING: A Text-Book for Students preparing for Examination or for Survey-work in the Colonies. By GEORGE W. USILL, A.M.I.C.E., Author of "The Statistics of the Water Supply of Great Britain." With Four Lithographic Plates and upwards of 330 Illustrations. Second Edition, Revised. Crown 8vo, 7*s.* 6*d.* cloth. [*Just published.*

"The best forms of instruments are described as to their construction, uses and modes of employment, and there are innumerable hints on work and equipment such as the author, in his experience as surveyor, draughtsman and teacher, has found necessary, and which the student in his inexperience will find most serviceable."—*Engineer.*

"The latest treatise in the English language on surveying, and we have no hesitation in saying that the student will find it a better guide than any of its predecessors . . . . . Deserves to be recognised as the first book which should be put in the hands of a pupil of Civil Engineering, and every gentleman of education who sets out for the Colonies would find it well to have a copy."—*Architect.*

"A very useful, practical handbook on field practice. Clear, accurate and not too condensed."—*Journal of Education.*

Survey Practice.

AID TO SURVEY PRACTICE, for Reference in Surveying, Levelling, and Setting-out; and in Route Surveys of Travellers by Land and Sea. With Tables, Illustrations, and Records. By LOWIS D'A. JACKSON, A.M.I.C.E., Author of "Hydraulic Manual," "Modern Metrology," &c. Second Edition, Enlarged. Large crown 8vo, 12*s.* 6*d.* cloth.

"Mr. Jackson has produced a valuable *vade-mecum* for the surveyor. We can recommend this book as containing an admirable supplement to the teaching of the accomplished surveyor."—*Athenæum.*

"As a text-book we should advise all surveyors to place it in their libraries, and study well the matured instructions afforded in its pages."—*Colliery Guardian.*

"The author brings to his work a fortunate union of theory and practical experience which, aided by a clear and lucid style of writing, renders the book a very useful one."—*Builder.*

Surveying, Land and Marine.

LAND AND MARINE SURVEYING, in Reference to the Preparation of Plans for Roads and Railways; Canals, Rivers, Towns' Water Supplies; Docks and Harbours. With Description and Use of Surveying Instruments. By W. D. HASKOLL, C.E., Author of "Bridge and Viaduct Construction," &c. Second Edition, Revised, with Additions. Large cr. 8vo, 9*s.* cl.

"This book must prove of great value to the student. We have no hesitation in recommending it, feeling assured that it will more than repay a careful study."—*Mechanical World.*

"A most useful and well arranged book for the aid of a student. We can strongly recommend it as a carefully-written and valuable text-book. It enjoys a well-deserved repute among surveyors." —*Builder.*

"This volume cannot fail to prove of the utmost practical utility. It may be safely recommended to all students who aspire to become clean and expert surveyors."—*Mining Journal.*

Tunnelling.

PRACTICAL TUNNELLING. Explaining in detail the Setting-out of the works, Shaft-sinking and Heading-driving, Ranging the Lines and Levelling underground, Sub-Excavating, Timbering, and the Construction of the Brickwork of Tunnels, with the amount of Labour required for, and the Cost of, the various portions of the work. By FREDERICK W. SIMMS, F.G.S., M.Inst.C.E. Third Edition, Revised and Extended by D. KINNEAR CLARK, M.Inst.C.E. Imperial 8vo, with 21 Folding Plates and numerous Wood Engravings, 30*s.* cloth.

"The estimation in which Mr. Simms's book on tunnelling has been held for over thirty years cannot be more truly expressed than in the words of the late Prof. Rankine:—'The best source of information on the subject of tunnels is Mr. F. W. Simms's work on Practical Tunnelling.'"—*Architect.*

"It has been regarded from the first as a text book of the subject. . . . Mr. Clarke has added immensely to the value of the book."—*Engineer.*

Levelling.

A TREATISE ON THE PRINCIPLES AND PRACTICE OF LEVELLING. Showing its Application to purposes of Railway and Civil Engineering, in the Construction of Roads; with Mr. Telford's Rules for the same. By Frederick W. Simms, F.G.S., M.Inst.C.E. Seventh Edition, with the addition of Law's Practical Examples for Setting-out Railway Curves, and Trautwine's Field Practice of Laying-out Circular Curves. With 7 Plates and numerous Woodcuts, 8vo, 8*s.* 6*d.* cloth. *** Trautwine on Curves may be had separate, 5*s.*

"The text-book on levelling in most of our engineering schools and colleges."—*Engineer.*

"The publishers have rendered a substantial service to the profession, especially to the younger members, by bringing out the present edition of Mr. Simms's useful work."—*Engineering.*

Heat, Expansion by.

EXPANSION OF STRUCTURES BY HEAT. By John Keily, C.E., late of the Indian Public Works and Victorian Railway Departments. Crown 8vo, 3*s.* 6*d.* cloth.

Summary of Contents.

Section I. Formulas and Data.
Section II. Metal Bars.
Section III. Simple Frames.
Section IV. Complex Frames and Plates.
Section V. Thermal Conductivity.
Section VI. Mechanical Force of Heat.
Section VII. Work of Expansion and Contraction.
Section VIII. Suspension Bridges.
Section IX. Masonry Structures.

"The aim the author has set before him, viz., to show the effects of heat upon metallic and other structures, is a laudable one, for this is a branch of physics upon which the engineer or architect can find but little reliable and comprehensive data in books."—*Builder.*

"Whoever is concerned to know the effect of changes of temperature on such structures as suspension bridges and the like, could not do better than consult Mr. Keily's valuable and handy exposition of the geometrical principles involved in these changes."—*Scotsman.*

Practical Mathematics.

MATHEMATICS FOR PRACTICAL MEN: Being a Common-place Book of Pure and Mixed Mathematics. Designed chiefly for the use of Civil Engineers, Architects and Surveyors. By Olinthus Gregory, LL.D., F.R.A.S., Enlarged by Henry Law, C.E. 4th Edition, carefully Revised by J. R. Young, formerly Professor of Mathematics, Belfast College. With 13 Plates, 8vo, £1 1*s.* cloth.

"The engineer or architect will here find ready to his hand rules for solving nearly every mathematical difficulty that may arise in his practice The rules are in all cases explained by means of examples, in which every step of the process is clearly worked out."—*Builder.*

One of the most serviceable books for practical mechanics. . . It is an instructive book for the student, and a text-book for him who, having once mastered the subjects it treats of, needs occasionally to refresh his memory upon them."—*Building News.*

Hydraulic Tables.

HYDRAULIC TABLES, CO-EFFICIENTS, and FORMULÆ for finding the Discharge of Water from Orifices, Notches, Weirs, Pipes, and Rivers. With New Formulæ, Tables, and General Information on Rainfall, Catchment-Basins, Drainage, Sewerage, Water Supply for Towns and Mill Power. By John Neville, Civil Engineer, M.R.I.A. Third Ed., carefully Revised, with considerable Additions. Numerous Illusts. Cr. 8vo, 14*s.* cloth.

"Alike valuable to students and engineers in practice; its study will prevent the annoyance of avoidable failures, and assist them to select the readiest means of successfully carrying out any given work connected with hydraulic engineering."—*Mining Journal.*

"It is, of all English books on the subject, the one nearest to completeness. . . . From the good arrangement of the matter, the clear explanations, and abundance of formulæ, the carefully calculated tables, and, above all, the thorough acquaintance with both theory and construction, which is displayed from first to last, the book will be found to be an acquisition."—*Architect.*

Hydraulics.

HYDRAULIC MANUAL. Consisting of Working Tables and Explanatory Text. Intended as a Guide in Hydraulic Calculations and Field Operations. By Lowis D'A. Jackson, Author of "Aid to Survey Practice," "Modern Metrology," &c. Fourth Edition, Enlarged. Large cr. 8vo, 16*s.* cl.

"The author has had a wide experience in hydraulic engineering and has been a careful observer of the facts which have come under his notice, and from the great mass of material at his command he has constructed a manual which may be accepted as a trustworthy guide to this branch of the engineer's profession. We can heartily recommend this volume to all who desire to be acquainted with the latest development of this important subject."—*Engineering.*

"The standard-work in this department of mechnnics.'—*Scotsman.*

"The most useful feature of this work is its freedom from what is superannuated, and its thorough adoption of recent experiments; the text is, in fact, in great part a short account of the great modern experiments."—*Nature.*

Drainage.

ON THE DRAINAGE OF LANDS, TOWNS AND BUILDINGS. By G. D. DEMPSEY, C.E., Author of "The Practical Railway Engineer," &c. Revised, with large Additions on RECENT PRACTICE IN DRAINAGE ENGINEERING, by D. KINNEAR CLARK, M.Inst.C.E. Author of "Tramways: Their Construction and Working," "A Manual of Rules, Tables, and Data for Mechanical Engineers," &c. &c. Crown 8vo, 7*s.* 6*d.* cloth. [*Just published.*

"The new matter added to Mr. Dempsey's excellent work is characterised by the comprehensive grasp and accuracy of detail for which the name of Mr. D. K. Clark is a sufficient voucher."—*Athenæum.*

"As a work on recent practice in drainage engineering, the book is to be commended to all who are making that branch of engineering science their special study."—*Iron.*

"A comprehensive manual on drainage engineering, and a useful introduction to the student." *Building News.*

Tramways and their Working.

TRAMWAYS: THEIR CONSTRUCTION AND WORKING. Embracing a Comprehensive History of the System; with an exhaustive Analysis of the various Modes of Traction, including Horse-Power, Steam, Heated Water, and Compressed Air; a Description of the Varieties of Rolling Stock; and ample Details of Cost and Working Expenses: the Progress recently made in Tramway Construction, &c. &c. By D. KINNEAR CLARK, M.Inst.C.E. With over 200 Wood Engravings, and 13 Folding Plates. Two Vols., large crown 8vo, 30*s.* cloth.

"All interested in tramways must refer to it, as all railway engineers have turned to the author's work 'Railway Machinery.'"—*Engineer.*

"An exhaustive and practical work on tramways, in which the history of this kind of locomotion, and a description and cost of the various modes of laying tramways, are to be found."—*Building News.*

"The best form of rails, the best mode of construction, and the best mechanical appliances are so fairly indicated in the work under review, that any engineer about to construct a tramway will be enabled at once to obtain the practical information which will be of most service to him."—*Athenæum.*

Oblique Arches.

A PRACTICAL TREATISE ON THE CONSTRUCTION OF OBLIQUE ARCHES. By JOHN HART. Third Edition, with Plates. Imperial 8vo, 8*s.* cloth.

Curves, Tables for Setting-out.

TABLES OF TANGENTIAL ANGLES AND MULTIPLES for Setting-out Curves from 5 to 200 Radius. By ALEXANDER BEAZELEY, M.Inst.C.E. Third Edition. Printed on 48 Cards, and sold in a cloth box, waistcoat-pocket size, 3*s.* 6*d.*

"Each table is printed on a small card, which, being placed on the theodolite, leaves the hands free to manipulate the instrument—no small advantage as regards the rapidity of work."—*Engineer.*

"Very handy; a man may know that all his day's work must fall on two of these cards, which he puts into his own card-case, and leaves the rest behind."—*Athenæum.*

Earthwork.

EARTHWORK TABLES. Showing the Contents in Cubic Yards of Embankments, Cuttings, &c., of Heights or Depths up to an average of 80 feet. By JOSEPH BROADBENT, C.E., and FRANCIS CAMPIN, C.E. Crown 8vo, 5*s.* cloth.

"The way in which accuracy is attained, by a simple division of each cross section into three elements, two in which are constant and one variable, is ingenious."—*Athenæum.*

Tunnel Shafts.

THE CONSTRUCTION OF LARGE TUNNEL SHAFTS: A Practical and Theoretical Essay. By J. H. WATSON BUCK, M.Inst.C.E., Resident Engineer, London and North-Western Railway. Illustrated with Folding Plates, royal 8vo, 12*s.* cloth.

"Many of the methods given are of extreme practical value to the mason; and the observations on the form of arch, the rules for ordering the stone, and the construction of the templates will be found of considerable use. We commend the book to the engineering profession."—*Building News.*

"Will be regarded by civil engineers as of the utmost value, and calculated to save much time and obviate many mistakes."—*Colliery Guardian.*

Girders, Strength of.

GRAPHIC TABLE FOR FACILITATING THE COMPUTATION OF THE WEIGHTS OF WROUGHT IRON AND STEEL GIRDERS, etc., for Parliamentary and other Estimates. By J. H. WATSON BUCK, M.Inst.C.E. On a Sheet, 2*s.* 6*d.*

River Engineering.

RIVER BARS: The Causes of their Formation, and their Treatment by "Induced Tidal Scour;" with a Description of the Successful Reduction by this Method of the Bar at Dublin. By I. J. MANN, Assist. Eng. to the Dublin Port and Docks Board. Royal 8vo, 7*s.* 6*d.* cloth.

"We recommend all interested in harbour works—and, indeed, those concerned in the improvements of rivers generally—to read Mr. Mann's interesting work on the treatment of river bars."—*Engineer.*

Trusses.

TRUSSES OF WOOD AND IRON. Practical Applications of Science in Determining the Stresses, Breaking Weights, Safe Loads, Scantlings, and Details of Construction, with Complete Working Drawings. By WILLIAM GRIFFITHS, Surveyor, Assistant Master, Tranmere School of Science and Art. Oblong 8vo, 4*s.* 6*d.* cloth.

"This handy little book enters so minutely into every detail connected with the construction o roof trusses, that no student need be ignorant of these matters."—*Practical Engineer.*

Railway Working.

SAFE RAILWAY WORKING. A Treatise on Railway Accidents: Their Cause and Prevention; with a Description of Modern Appliances and Systems. By CLEMENT E. STRETTON, C.E., Vice-President and Consulting Engineer, Amalgamated Society of Railway Servants. With Illustrations and Coloured Plates. Second Edition, Enlarged. Crown 8vo, 3*s.* 6*d.* cloth. [*Just published.*

"A book for the engineer, the directors, the managers; and, in short, all who wish for information on railway matters will find a perfect encyclopædia in 'Safe Railway Working.'"—*Railway Review.*

"We commend the remarks on railway signalling to all railway managers, especially where a uniform code and practice is advocated."—*Herepath's Railway Journal.*

"The author may be congratulated on having collected, in a very convenient form, much valuable information on the principal questions affecting the safe working of railways."—*Railway Engineer.*

Field-Book for Engineers.

THE ENGINEER'S, MINING SURVEYOR'S, AND CONTRACTOR'S FIELD-BOOK. Consisting of a Series of Tables, with Rules, Explanations of Systems, and use of Theodolite for Traverse Surveying and Plotting the Work with minute accuracy by means of Straight Edge and Set Square only; Levelling with the Theodolite, Casting-out and Reducing Levels to Datum, and Plotting Sections in the ordinary manner; setting-out Curves with the Theodolite by Tangential Angles and Multiples, with Right and Left-hand Readings of the Instrument: Setting-out Curves without Theodolite, on the System of Tangential Angles by sets of Tangents and Offsets; and Earthwork Tables to 80 feet deep, calculated for every 6 inches in depth. By W. DAVIS HASKOLL, C.E. With numerous Woodcuts. Fourth Edition, Enlarged. Crown 8vo, 12*s.* cloth.

"The book is very handy; the separate tables of sines and tangents to every minute will make it useful for many other purposes, the genuine traverse tables existing all the same."—*Athenæum.*

"Every person engaged in engineering field operations will estimate the importance of such a work and the amount of valuable time which will be saved by reference to a set of reliable tables prepared with the accuracy and fulness of those given in this volume."—*Railway News.*

Earthwork, Measurement of.

A MANUAL ON EARTHWORK. By ALEX. J. S. GRAHAM, C.E. With numerous Diagrams. Second Edition. 18mo, 2*s.* 6*d.* cloth.

"A great amount of practical information, very admirably arranged, and available for rough estimates, as well as for the more exact calculations required in the engineer's and contractor's offices."—*Artisan.*

Strains in Ironwork.

THE STRAINS ON STRUCTURES OF IRONWORK; with Practical Remarks on Iron Construction. By F. W. SHEILDS, M.Inst.C.E. Second Edition, with 5 Plates. Royal 8vo, 5*s.* cloth.

"The student cannot find a better little book on this subject."—*Engineer.*

Cast Iron and other Metals, Strength of.

A PRACTICAL ESSAY ON THE STRENGTH OF CAST IRON AND OTHER METALS. By THOMAS TREDGOLD, C.E. Fifth Edition, including HODGKINSON'S Experimental Researches. 8vo, 12*s.* cloth.

ARCHITECTURE, BUILDING, etc.

Construction.

THE SCIENCE OF BUILDING: An Elementary Treatise on the Principles of Construction. By E. Wyndham Tarn, M.A., Architect. Third Edition, Revised and Enlarged, with 59 Engravings. Fcap. 8vo, 4*s.* cloth. [*Just published.*

"A very valuable book, which we strongly recommend to all students."—*Builder.*

"No architectural student should be without this handbook of constructional knowledge."—*Architect.*

Villa Architecture.

A HANDY BOOK OF VILLA ARCHITECTURE: Being a Series of Designs for Villa Residences in various Styles. With Outline Specifications and Estimates. By C. Wickes, Architect, Author of "The Spires and Towers of England," &c. 61 Plates, 4to, £1 11*s.* 6*d.* half-morocco, gilt edges.

"The whole of the designs bear evidence of their being the work of an artistic architect, and they will prove very valuable and suggestive."—*Building News.*

Text-Book for Architects.

THE ARCHITECT'S GUIDE: Being a Text-Book of Useful Information for Architects, Engineers, Surveyors, Contractors, Clerks of Works, &c. &c. By Frederick Rogers, Architect, Author of "Specifications for Practical Architecture," &c. Second Edition, Revised and Enlarged. With numerous Illustrations. Crown 8vo, 6*s.* cloth.

"As a text-book of useful information for architects, engineers, surveyors, &c., it would be hard to find a handier or more complete little volume."—*Standard.*

"A young architect could hardly have a better guide-book."—*Timber Trades Journal.*

Taylor and Cresy's Rome.

THE ARCHITECTURAL ANTIQUITIES OF ROME. By the late G. L. Taylor, Esq., F.R.I.B.A., and Edward Cresy, Esq. New Edition, thoroughly Revised by the Rev. Alexander Taylor, M.A. (son of the late G. L. Taylor, Esq.), Fellow of Queen's College, Oxford, and Chaplain of Gray's Inn. Large folio, with 130 Plates, half-bound, £3 3*s.*

N.B.—This is the only book which gives on a large scale, and with the precision of architectural measurement, the principal Monuments of Ancient Rome in plan, elevation, and detail.

"Taylor and Cresy's work has from its first publication been ranked among those professional books which cannot be bettered. . . . It would be difficult to find examples of drawings, even among those of the most painstaking students of Gothic, more thoroughly worked out than are the one hundred and thirty plates in this volume."—*Architect.*

Architectural Drawing.

PRACTICAL RULES ON DRAWING, for the Operative Builder and Young Student in Architecture. By George Pyne. With 14 Plates, 4to, 7*s.* 6*d.* boards.

Sir Wm. Chambers's Treatise on Civil Architecture.

THE DECORATIVE PART OF CIVIL ARCHITECTURE. By Sir William Chambers, F.R.S. With Portrait, Illustrations, Notes, and an Examination of Grecian Architecture, by Joseph Gwilt, F.S.A. Revised and Edited by W. H. Leeds, with a Memoir of the Author. 66 Plates, 4to, 21*s.* cloth.

House Building and Repairing.

THE HOUSE-OWNER'S ESTIMATOR; or, What will it Cost to Build, Alter, or Repair? A Price Book adapted to the Use of Unprofessional People, as well as for the Architectural Surveyor and Builder. By James D. Simon, A.R.I.B.A. Edited and Revised by Francis T. W. Miller, A.R.I.B.A. With numerous Illustrations. Fourth Edition, Revised. Crown 8vo, 3*s.* 6*d.* cloth.

"In two years it will repay its cost a hundred times over."—*Field.*

"A very handy book."—*English Mechanic.*

Cottages and Villas.

COUNTRY AND SUBURBAN COTTAGES AND VILLAS: How to Plan and Build Them. Containing 33 Plates, with Introduction, General Explanations, and Description of each Plate. By James W. Bogue, Architect, Author of "Domestic Architecture," &c. 4to, 10*s.* 6*d.* cloth. [*Just published.*

The New Builder's Price Book, 1891.

LOCKWOOD'S BUILDER'S PRICE BOOK FOR 1891. A Comprehensive Handbook of the Latest Prices and Data for Builders, Architects, Engineers and Contractors. Re-constructed, Re-written and Greatly Enlarged. By FRANCIS T. W. MILLER. 640 closely-printed pages, crown 8vo, 4*s.* cloth. [*Just published.*

"This book is a very useful one, and should find a place in every English office connected with the building and engineering professions."—*Industries.*

"This Price Book has been set up in new type. . . . Advantage has been taken of the transformation to add much additional information, and the volume is now an excellent book of reference."—*Architect.*

"In its new and revised form this Price Book is what a work of this kind should be—comprehensive, reliable, well arranged, legible and well bound."—*British Architect.*

"A work of established reputation."—*Athenæum.*

"This very useful handbook is well written, exceedingly clear in its explanations and great care has evidently been taken to ensure accuracy."—*Morning Advertiser*

Designing, Measuring, and Valuing.

THE STUDENT'S GUIDE to the PRACTICE of MEASURING AND VALUING ARTIFICERS' WORKS. Containing Directions for taking Dimensions, Abstracting the same, and bringing the Quantities into Bill, with Tables of Constants for Valuation of Labour, and for the Calculation of Areas and Solidities. Originally edited by EDWARD DOBSON, Architect. With Additions on Mensuration and Construction, and a New Chapter on Dilapidations, Repairs, and Contracts, by E. WYNDHAM TARN, M.A. Sixth Edition, including a Complete Form of a Bill of Quantities. With 8 Plates and 63 Woodcuts. Crown 8vo, 7*s.* 6*d.* cloth.

"Well fulfils the promise of its title-page, and we can thoroughly recommend it to the class for whose use it has been compiled. Mr. Tarn's additions and revisions have much increased the usefulness of the work, and have especially augmented its value to students."—*Engineering.*

"This edition will be found the most complete treatise on the principles of measuring and valuing artificers' work that has yet been published."—*Building News.*

Pocket Estimator and Technical Guide.

THE POCKET TECHNICAL GUIDE, MEASURER AND ESTIMATOR FOR BUILDERS AND SURVEYORS. Containing Technical Directions for Measuring Work in all the Building Trades, Complete Specifications for Houses, Roads, and Drains, and an easy Method of Estimating the parts of a Building collectively. By A. C. BEATON, Author of "Quantities and Measurements," &c. Fifth Edition. With 53 Woodcuts, waistcoat-pocket size, 1*s.* 6*d.* gilt edges.

"No builder, architect, surveyor, or valuer should be without his 'Beaton.'"—*Building News.*

"Contains an extraordinary amount of information in daily requisition in measuring and estimating. Its presence in the pocket will save valuable time and trouble."—*Building World.*

Donaldson on Specifications.

THE HANDBOOK OF SPECIFICATIONS; or, Practical Guide to the Architect, Engineer, Surveyor, and Builder, in drawing up Specifications and Contracts for Works and Constructions. Illustrated by Precedents of Buildings actually executed by eminent Architects and Engineers. By Professor T. L. DONALDSON, P.R.I.B.A., &c. New Edition, in One large Vol., 8vo, with upwards of 1,000 pages of Text, and 33 Plates, £1 11*s.* 6*d.* cloth.

"In this work forty-four specifications of executed works are given, including the specifications for parts of the new Houses of Parliament, by Sir Charles Barry, and for the new Royal Exchange, by Mr. Tite, M.P. The latter, in particular, is a very complete and remarkable document. It embodies, to a great extent, as Mr. Donaldson mentions, 'the bill of quantities with the description of the works.' . . . It is valuable as a record, and more valuable still as a book of precedents. . . . Suffice it to say that Donaldson's 'Handbook of Specifications' must be bought by all architects."—*Builder.*

Bartholomew and Rogers' Specifications.

SPECIFICATIONS FOR PRACTICAL ARCHITECTURE. A Guide to the Architect, Engineer, Surveyor, and Builder. With an Essay on the Structure and Science of Modern Buildings. Upon the Basis of the Work by ALFRED BARTHOLOMEW, thoroughly Revised, Corrected, and greatly added to by FREDERICK ROGERS, Architect. Second Edition, Revised, with Additions. With numerous Illustrations, medium 8vo, 15*s.* cloth.

"The collection of specifications prepared by Mr. Rogers on the basis of Bartholomew's work is too well known to need any recommendation from us. It is one of the books with which every young architect must be equipped; for time has shown that the specifications cannot be set aside through any defect in them."—*Architect.*

Building; Civil and Ecclesiastical.

A BOOK ON BUILDING, Civil and Ecclesiastical, including Church Restoration; with the Theory of Domes and the Great Pyramid, &c. By Sir EDMUND BECKETT, Bart., LL.D., F.R.A.S., Author of "Clocks and Watches, and Bells," &c. Second Edition, Enlarged. Fcap. 8vo, 5*s.* cloth.

"A book which is always amusing and nearly always instructive. The style throughout is in the highest degree condensed and epigrammatic."—*Times.*

Ventilation of Buildings.

VENTILATION. A Text Book to the Practice of the Art of Ventilating Buildings. With a Chapter upon Air Testing. By W. P. BUCHAN, R.P., Sanitary and Ventilating Engineer, Author of "Plumbing," &c. With 170 Illustrations. 12mo, 4*s.* cloth boards. [*Just published.*

The Art of Plumbing.

PLUMBING. A Text Book to the Practice of the Art or Craft of the Plumber, with Supplementary Chapters on House Drainage, embodying the latest Improvements. By WILLIAM PATON BUCHAN, R.P., Sanitary Engineer and Practical Plumber. Fifth Edition, Enlarged to 370 pages, and 380 Illustrations. 12mo, 4*s.* cloth boards.

"A text book which may be safely put in the hands of every young plumber, and which will also be found useful by architects and medical professors."—*Builder.*

"A valuable text book, and the only treatise which can be regarded as a really reliable manua of the plumber's art."—*Building News.*

Geometry for the Architect, Engineer, etc.

PRACTICAL GEOMETRY, for the Architect, Engineer and Mechanic. Giving Rules for the Delineation and Application of various Geometrical Lines, Figures and Curves. By E. W. TARN, M.A., Architect, Author of "The Science of Building," &c. Second Edition. With 172 Illustrations, demy 8vo, 9*s.* cloth.

"No book with the same objects in view has ever been published in which the clearness of the rules laid down and the illustrative diagrams have been so satisfactory."—*Scotsman.*

The Science of Geometry.

THE GEOMETRY OF COMPASSES; or, Problems Resolved by the mere Description of Circles, and the use of Coloured Diagrams and Symbols. By OLIVER BYRNE. Coloured Plates. Crown 8vo, 3*s.* 6*d.* cloth.

"The treatise is a good one, and remarkable—like all Mr. Byrne's contributions to the science of geometry—for the lucid character of its teaching."—*Building News.*

DECORATIVE ARTS, etc.

Woods and Marbles (Imitation of).

SCHOOL OF PAINTING FOR THE IMITATION OF WOODS AND MARBLES, as Taught and Practised by A. R. VAN DER BURG and P. VAN DER BURG, Directors of the Rotterdam Painting Institution. Royal folio, 18½ by 12½ in., Illustrated with 24 full-size Coloured Plates; also 12 plain Plates, comprising 154 Figures. Second and Cheaper Edition. Price £1 11*s.* 6*d.*

List of Plates.

1. Various Tools required for Wood Painting—2, 3. Walnut: Preliminary Stages of Graining and Finished Specimen—4. Tools used for Marble Painting and Method of Manipulation—5, 6. St. Remi Marble: Earlier Operations and Finished Specimen—7. Methods of Sketching different Grains, Knots, &c.—8, 9. Ash: Preliminary Stages and Finished Specimen—10. Methods of Sketching Marble Grains—11, 12. Breche Marble: Preliminary Stages of Working and Finished Specimen—13. Maple: Methods of Producing the different Grains—14, 15. Bird's-eye Maple: Preliminary Stages and Finished Specimen—16. Methods of Sketching the different Species of White Marble—17, 18. White Marble: Preliminary Stages of Process and Finished Specimen—19. Mahogany: Specimens of various Grains and Methods of Manipulation—20, 21. Mahogany: Earlier Stages and Finished Specimen—22, 23, 24. Sienna Marble: Varieties of Grain, Preliminary Stages and Finished Specimen—25, 26, 27. Juniper Wood: Methods of producing Grain, &c.: Preliminary Stages and Finished Specimen—28, 29, 30. Vert de Mer Marble: Varieties of Grain and Methods of Working Unfinished and Finished Specimens—31. 32. 33. Oak: Varieties of Grain, Tools Employed, and Methods of Manipulation, Preliminary Stages and Finished Specimen—34, 35, 36. Waulsort Marble: Varieties of Grain, Unfinished and Finished Specimens.

*** OPINIONS OF THE PRESS.

"Those who desire to attain skill in the art of painting woods and marbles will find advantage in consulting this book. . . . Some of the Working Men's Clubs should give their young men the opportunity to study it."—*Builder.*

"A comprehensive guide to the art. The explanations of the processes, the manipulation and management of the colours, and the beautifully executed plates will not be the least valuable to the student who aims at making his work a faithful transcript of nature."—*Building News.*

House Decoration.

ELEMENTARY DECORATION. A Guide to the Simpler Forms of Everyday Art, as applied to the Interior and Exterior Decoration of Dwelling Houses, &c. By JAMES W. FACEY, Jun. With 68 Cuts. 12mo, 2s. cloth limp.

PRACTICAL HOUSE DECORATION: A Guide to the Art of Ornamental Painting, the Arrangement of Colours in Apartments, and the principles of Decorative Design. With some Remarks upon the Nature and Properties of Pigments. By JAMES WILLIAM FACEY, Author of "Elementary Decoration," &c. With numerous Illustrations. 12mo, 2s. 6d. cloth limp.

N.B.—The above Two Works together in One Vol., strongly half-bound, 5s.

Colour.

A GRAMMAR OF COLOURING. Applied to Decorative Painting and the Arts. By GEORGE FIELD. New Edition, Revised, Enlarged, and adapted to the use of the Ornamental Painter and Designer. By ELLIS A. DAVIDSON. With New Coloured Diagrams and Engravings. 12mo, 3s. 6d. cloth boards.

"The book is a most useful *resumé* of the properties of pigments."—*Builder.*

House Painting, Graining, etc.

HOUSE PAINTING, GRAINING, MARBLING, AND SIGN WRITING, A Practical Manual of. By ELLIS A. DAVIDSON. Fifth Edition. With Coloured Plates and Wood Engravings. 12mo, 6s. cloth boards.

"A mass of information, of use to the amateur and of value to the practical man."—*English Mechanic.*

"Simply invaluable to the youngster entering upon this particular calling, and highly serviceable to the man who is practising it."—*Furniture Gazette.*

Decorators, Receipts for.

THE DECORATOR'S ASSISTANT: A Modern Guide to Decorative Artists and Amateurs, Painters, Writers, Gilders, &c. Containing upwards of 600 Receipts, Rules and Instructions; with a variety of Information for General Work connected with every Class of Interior and Exterior Decorations, &c. Fourth Edition, Revised. 152 pp., crown 8vo, 1s. in wrapper.

"Full of receipts of value to decorators, painters, gilders, &c. The book contains the gist of larger treatises on colour and technical processes. It would be difficult to meet with a work so full of varied information on the painter's art."—*Building News.*

"We recommend the work to all who, whether for pleasure or profit, require a guide to decoration."—*Plumber and Decorator.*

Moyr Smith on Interior Decoration.

ORNAMENTAL INTERIORS, ANCIENT AND MODERN. By J. MOYR SMITH. Super-royal 8vo, with 32 full-page Plates and numerous smaller Illustrations, handsomely bound in cloth, gilt top, price 18s.

"The book is well illustrated and handsomely got up, and contains some true criticism and a good many good examples of decorative treatment."—*The Builder.*

"This is the most elaborate and beautiful work on the artistic decoration of interiors that we have seen. . . . The scrolls, panels and other designs from the author's own pen are very beautiful and chaste; but he takes care that the designs of other men shall figure even more than his own."—*Liverpool Albion.*

"To all who take an interest in elaborate domestic ornament this handsome volume will be welcome."—*Graphic.*

British and Foreign Marbles.

MARBLE DECORATION and the Terminology of British and Foreign Marbles. A Handbook for Students. By GEORGE H. BLAGROVE, Author of "Shoring and its Application," &c. With 28 Illustrations. Crown 8vo, 3s. 6d. cloth.

"This most useful and much wanted handbook should be in the hands of every architect and builder."—*Building World.*

"It is an excellent manual for students, and interesting to artistic readers generally."—*Saturday Review.*

"A carefully and usefully written treatise; the work is essentially practical."—*Scotsman.*

Marble Working, etc.

MARBLE AND MARBLE WORKERS: A Handbook for Architects, Artists, Masons and Students. By ARTHUR LEE, Author of "A Visit to Carrara," "The Working of Marble," &c. Small crown 8vo, 2s. cloth.

"A really valuable addition to the technical literature of architects and masons."—*Building News.*

DELAMOTTE'S WORKS ON ILLUMINATION AND ALPHABETS.

A PRIMER OF THE ART OF ILLUMINATION, for the Use of Beginners: with a Rudimentary Treatise on the Art, Practical Directions for its exercise, and Examples taken from Illuminated MSS., printed in Gold and Colours. By F. DELAMOTTE. New and Cheaper Edition. Small 4to, 6*s.* ornamental boards.

"The examples of ancient MSS. recommended to the student, which, with much good sense, the author chooses from collections accessible to all, are selected with judgment and knowledge, as well as taste."—*Athenæum.*

ORNAMENTAL ALPHABETS, Ancient and Mediæval, from the Eighth Century, with Numerals; including Gothic, Church-Text, large and small, German, Italian, Arabesque, Initials for Illumination, Monograms, Crosses, &c. &c., for the use of Architectural and Engineering Draughtsmen, Missal Painters, Masons, Decorative Painters, Lithographers, Engravers, Carvers, &c. &c. Collected and Engraved by F. DELAMOTTE, and printed in Colours. New and Cheaper Edition. Royal 8vo, oblong, 2*s.* 6*d.* ornamental boards.

"For those who insert enamelled sentences round gilded chalices, who blazon shop legends over shop-doors, who letter church walls with pithy sentences from the Decalogue, this book will be useful."—*Athenæum.*

EXAMPLES OF MODERN ALPHABETS, Plain and Ornamental; including German, Old English, Saxon, Italic, Perspective, Greek, Hebrew, Court Hand, Engrossing, Tuscan, Riband, Gothic, Rustic, and Arabesque; with several Original Designs, and an Analysis of the Roman and Old English Alphabets, large and small, and Numerals, for the use of Draughtsmen, Surveyors, Masons, Decorative Painters, Lithographers, Engravers, Carvers, &c. Collected and Engraved by F. DELAMOTTE, and printed in Colours. New and Cheaper Edition. Royal 8vo, oblong, 2*s.* 6*d.* ornamental boards.

"There is comprised in it every possible shape into which the letters of the alphabet and numerals can be formed, and the talent which has been expended in the conception of the various plain and ornamental letters is wonderful."—*Standard.*

MEDIÆVAL ALPHABETS AND INITIALS FOR ILLUMINATORS. By F. G. DELAMOTTE. Containing 21 Plates and Illuminated Title, printed in Gold and Colours. With an Introduction by J. WILLIS BROOKS. Fourth and Cheaper Edition. Small 4to, 4*s.* ornamental boards.

"A volume in which the letters of the alphabet come forth glorified in gilding and all the colours of the prism interwoven and intertwined and intermingled."—*Sun.*

THE EMBROIDERER'S BOOK OF DESIGN. Containing Initials, Emblems, Cyphers, Monograms, Ornamental Borders, Ecclesiastical Devices, Mediæval and Modern Alphabets, and National Emblems. Collected by F. DELAMOTTE, and printed in Colours. Oblong royal 8vo, 1*s.* 6*d.* ornamental wrapper.

"The book will be of great assistance to ladies and young children who are endowed with the art of plying the needle in this most ornamental and useful pretty work."—*East Anglian Times.*

Wood Carving.

INSTRUCTIONS IN WOOD-CARVING, for Amateurs; with Hints on Design. By A LADY. With Ten Plates. New and Cheaper Edition. Crown 8vo, 2*s.* in emblematic wrapper.

"The handicraft of the wood-carver, so well as a book can impart it, may be learnt from 'A Lady's' publication."—*Athenæum.*

"The directions given are plain and easily understood."—*English Mechanic.*

Glass Painting.

GLASS STAINING AND THE ART OF PAINTING ON GLASS. From the German of Dr. GESSERT and EMANUEL OTTO FROMBERG. With an Appendix on THE ART OF ENAMELLING. 12mo, 2*s.* 6*d.* cloth limp.

Letter Painting.

THE ART OF LETTER PAINTING MADE EASY. By JAMES GREIG BADENOCH. With 12 full-page Engravings of Examples, 1*s.* 6*d.* cloth limp.

"The system is a simple one, but quite original, and well worth the careful attention of letter painters. It can be easily mastered and remembered."—*Building News.*

CARPENTRY, TIMBER, etc.

Tredgold's Carpentry, Revised & Enlarged by Tarn.

THE ELEMENTARY PRINCIPLES OF CARPENTRY. A Treatise on the Pressure and Equilibrium of Timber Framing, the Resistance of Timber, and the Construction of Floors, Arches, Bridges, Roofs, Uniting Iron and Stone with Timber, &c. To which is added an Essay on the Nature and Properties of Timber, &c., with Descriptions of the kinds of Wood used in Building; also numerous Tables of the Scantlings of Timber for different purposes, the Specific Gravities of Materials, &c. By THOMAS TREDGOLD, C.E. With an Appendix of Specimens of Various Roofs of Iron and Stone, Illustrated. Seventh Edition, thoroughly revised and considerably enlarged by E. WYNDHAM TARN, M.A., Author of "The Science of Building," &c. With 61 Plates, Portrait of the Author, and several Woodcuts. In one large vol., 4to, price £1 5s. cloth.

"Ought to be in every architect's and every builder's library."—*Builder.*

"A work whose monumental excellence must commend it wherever skilful carpentry is concerned. The author's principles are rather confirmed than impaired by time. The additional plates are of great intrinsic value."—*Building News.*

Woodworking Machinery.

WOODWORKING MACHINERY: Its Rise, Progress, and Construction. With Hints on the Management of Saw Mills and the Economical Conversion of Timber. Illustrated with Examples of Recent Designs by leading English, French, and American Engineers. By M. POWIS BALE, A.M.Inst.C.E.,M.I.M.E. Large crown 8vo, 12s. 6d. cloth.

"Mr. Bale is evidently an expert on the subject and he has collected so much information that his book is all-sufficient for builders and others engaged in the conversion of timber."—*Architect.*

"The most comprehensive compendium of wood-working machinery we have seen. The author is a thorough master of his subject."—*Building News.*

"The appearance of this book at the present time will, we should think, give a considerable impetus to the onward march of the machinist engaged in the designing and manufacture of wood-working machines. It should be in the office of every wood-working factory."—*English Mechanic.*

Saw Mills.

SAW MILLS: Their Arrangement and Management, and the Economical Conversion of Timber. (A Companion Volume to "Woodworking Machinery.") By M. POWIS BALE. With numerous Illustrations. Crown 8vo, 10s. 6d. cloth.

"The *administration* of a large sawing establishment is discussed, and the subject examined from a financial standpoint. Hence the size, shape, order, and disposition of saw-mills and the like are gone into in detail, and the course of the timber is traced from its reception to its delivery in its converted state. We could not desire a more complete or practical treatise."—*Builder.*

"We highly recommend Mr. Bale's work to the attention and perusal of all those who are engaged in the art of wood conversion, or who are about building or remodelling saw-mills on improved principles."—*Building News.*

Carpentering.

THE CARPENTER'S NEW GUIDE; or, Book of Lines for Carpenters; comprising all the Elementary Principles essential for acquiring a knowledge of Carpentry. Founded on the late PETER NICHOLSON'S Standard Work. A New Edition, Revised by ARTHUR ASHPITEL, F.S.A. Together with Practical Rules on Drawing, by GEORGE PYNE. With 74 Plates, 4to, £1 1s. cloth.

Handrailing and Stairbuilding.

A PRACTICAL TREATISE ON HANDRAILING: Showing New and Simple Methods for Finding the Pitch of the Plank, Drawing the Moulds, Bevelling, Jointing-up, and Squaring the Wreath. By GEORGE COLLINGS. Second Edition, Revised and Enlarged, to which is added A TREATISE ON STAIRBUILDING. With Plates and Diagrams. 12mo, 2s. 6d. cloth limp. [*Just published.*

"Will be found of practical utility in the execution of this difficult branch of joinery."—*Builder.*

"Almost every difficult phase of this somewhat intricate branch of joinery is elucidated by the aid of plates and explanatory letterpress."—*Furniture Gazette.*

Circular Work.

CIRCULAR WORK IN CARPENTRY AND JOINERY: A Practical Treatise on Circular Work of Single and Double Curvature. By GEORGE COLLINGS, Author of "A Practical Treatise on Handrailing." Illustrated with numerous Diagrams. Second Edition. 12mo, 2s. 6d. cloth limp.

"An excellent example of what a book of this kind should be. Cheap in price, clear in definition and practical in the examples selected."—*Builder.*

Timber Merchant's Companion.

THE TIMBER MERCHANT'S AND BUILDER'S COMPANION. Containing New and Copious Tables of the Reduced Weight and Measurement of Deals and Battens, of all sizes, from One to a Thousand Pieces, and the relative Price that each size bears per Lineal Foot to any given Price per Petersburg Standard Hundred; the Price per Cube Foot of Square Timber to any given Price per Load of 50 Feet; the proportionate Value of Deals and Battens by the Standard, to Square Timber by the Load of 50 Feet; the readiest mode of ascertaining the Price of Scantling per Lineal Foot of any size, to any given Figure per Cube Foot, &c. &c. By WILLIAM DOWSING. Fourth Edition, Revised and Corrected. Cr. 8vo, 3s. cl.

"Everything is as concise and clear as it can possibly be made. There can be no doubt that every timber merchant and builder ought to possess it."—*Hull Advertiser.*

"We are glad to see a fourth edition of these admirable tables, which for correctness and simplicity of arrangement leave nothing to be desired."—*Timber Trades Journal.*

"An exceedingly well-arranged, clear, and concise manual of tables for the use of all who buy or sell timber."—*Journal of Forestry.*

Practical Timber Merchant.

THE PRACTICAL TIMBER MERCHANT. Being a Guide for the use of Building Contractors, Surveyors, Builders, &c., comprising useful Tables for all purposes connected with the Timber Trade, Marks of Wood, Essay on the Strength of Timber, Remarks on the Growth of Timber, &c. By W. RICHARDSON. Fcap. 8vo, 3s. 6*d.* cloth.

"This handy manual contains much valuable information for the use of timber merchants, builders, foresters, and all others connected with the growth, sale, and manufacture of timber."—*Journal of Forestry.*

Timber Freight Book.

THE TIMBER MERCHANT'S, SAW MILLER'S, AND IMPORTER'S FREIGHT BOOK AND ASSISTANT. Comprising Rules, Tables, and Memoranda relating to the Timber Trade. By WILLIAM RICHARDSON, Timber Broker; together with a Chapter on "SPEEDS OF SAW MILL MACHINERY," by M. POWIS BALE, M.I.M.E., &c. 12mo, 3s. 6*d.* cl. boards.

"A very useful manual of rules, tables, and memoranda relating to the timber trade. We recommend it as a compendium of calculation to all timber measurers and merchants, and as supplying a real want in the trade."—*Building News.*

Packing-Case Makers, Tables for.

PACKING-CASE TABLES; showing the number of Superficial Feet in Boxes or Packing-Cases, from six inches square and upwards. By W. RICHARDSON, Timber Broker. Second Edition. Oblong 4to, 3*s.* 6*d.* cl.

"Invaluable labour-saving tables."—*Ironmonger.*

"Will save much labour and calculation."—*Grocer.*

Superficial Measurement.

THE TRADESMAN'S GUIDE TO SUPERFICIAL MEASUREMENT. Tables calculated from 1 to 200 inches in length, by 1 to 108 inches in breadth. For the use of Architects, Surveyors, Engineers, Timber Merchants, Builders, &c. By JAMES HAWKINGS. Third Edition. Fcap., 3*s.* 6*d.* cloth.

"A useful collection of tables to facilitate rapid calculation of surfaces. The exact area of any surface of which the limits have been ascertained can be instantly determined. The book will be found of the greatest utility to all engaged in building operations."—*Scotsman.*

"These tables will be found of great assistance to all who require to make calculations in superficial measurement."—*English Mechanic.*

Forestry.

THE ELEMENTS OF FORESTRY. Designed to afford Information concerning the Planting and Care of Forest Trees for Ornament or Profit, with Suggestions upon the Creation and Care of Woodlands. By F. B. HOUGH. Large crown 8vo, 10*s.* cloth.

Timber Importer's Guide.

THE TIMBER IMPORTER'S, TIMBER MERCHANT'S AND BUILDER'S STANDARD GUIDE. By RICHARD E. GRANDY. Comprising an Analysis of Deal Standards, Home and Foreign, with Comparative Values and Tabular Arrangements for fixing Nett Landed Cost on Baltic and North American Deals, including all intermediate Expenses, Freight, Insurance, &c. &c. Together with copious Information for the Retailer and Builder. Third Edition, Revised. 12mo, 2*s.* cloth limp.

"Everything it pretends to be: built up gradually, it leads one from a forest to a treenail, and throws in, as a makeweight, a host of material concerning bricks, columns, cisterns, &c."—*English Mechanic.*

MARINE ENGINEERING, NAVIGATION, etc.

Chain Cables.

CHAIN CABLES AND CHAINS. Comprising Sizes and Curves of Links, Studs, &c., Iron for Cables and Chains, Chain Cable and Chain Making, Forming and Welding Links, Strength of Cables and Chains, Certificates for Cables, Marking Cables, Prices of Chain Cables and Chains, Historical Notes, Acts of Parliament, Statutory Tests, Charges for Testing, List of Manufacturers of Cables, &c. &c. By THOMAS W. TRAILL, F.E.R.N., M. Inst. C.E., Engineer Surveyor in Chief, Board of Trade, Inspector of Chain Cable and Anchor Proving Establishments, and General Superintendent, Lloyd's Committee on Proving Establishments. With numerous Tables, Illustrations and Lithographic Drawings. Folio, £2 2s. cloth, bevelled boards.

"It contains a vast amount of valuable information. Nothing seems to be wanting to make it a complete and standard work of reference on the subject."—*Nautical Magazine.*

Marine Engineering.

MARINE ENGINES AND STEAM VESSELS (A Treatise on). By ROBERT MURRAY, C.E. Eighth Edition, thoroughly Revised, with considerable Additions by the Author and by GEORGE CARLISLE, C.E., Senior Surveyor to the Board of Trade at Liverpool. 12mo, 5s. cloth boards.

"Well adapted to give the young steamship engineer or marine engine and boiler maker a general introduction into his practical work."—*Mechanical World.*

"We feel sure that this thoroughly revised edition will continue to be as popular in the future as it has been in the past, as, for its size, it contains more useful information than any similar treatise."—*Industries.*

"As a compendious and useful guide to engineers of our mercantile and royal naval services we should say it cannot be surpassed."—*Building News.*

The information given is both sound and sensible, and well qualified to direct young sea-going hands on the straight road to the extra chief's certificate. Most useful to surveyors, inspectors, draughtsmen, and all young engineers who take an interest in their profession."—*Glasgow Herald.*

"An indispensable manual for the student of marine engineering."—*Liverpool Mercury.*

Pocket-Book for Naval Architects and Shipbuilders.

THE NAVAL ARCHITECT'S AND SHIPBUILDER'S POCKET-BOOK of Formulæ, Rules, and Tables, and MARINE ENGINEER'S AND SURVEYOR'S Handy Book of Reference. By CLEMENT MACKROW, Member of the Institution of Naval Architects, Naval Draughtsman. Fourth Edition, Revised. With numerous Diagrams, &c. Fcap., 12s. 6d. strongly bound in leather.

"Should be used by all who are engaged in the construction or design of vessels. . . . Will be found to contain the most useful tables and formulæ required by shipbuilders, carefully collected from the best authorities, and put together in a popular and simple form."—*Engineer.*

"The professional shipbuilder has now, in a convenient and accessible form, reliable data for solving many of the numerous problems that present themselves in the course of his work."—*Iron.*

"There is scarcely a subject on which a naval architect or shipbuilder can require to refresh his memory which will not be found within the covers of Mr. Mackrow's book."—*English Mechanic.*

Pocket-Book for Marine Engineers.

A POCKET-BOOK OF USEFUL TABLES AND FORMULÆ FOR MARINE ENGINEERS. By FRANK PROCTOR, A.I.N.A. Third Edition. Royal 32mo, leather, gilt edges, with strap, 4s.

"We recommend it to our readers as going far to supply a long-felt want."—*Naval Science.*

"A most useful companion to all marine engineers."—*United Service Gazette.*

Introduction to Marine Engineering.

ELEMENTARY ENGINEERING: A Manual for Young Marine Engineers and Apprentices. In the Form of Questions and Answers on Metals, Alloys, Strength of Materials, Construction and Management of Marine Engines and Boilers, Geometry, &c. &c. With an Appendix of Useful Tables. By JOHN SHERREN BREWER, Government Marine Surveyor, Hongkong. Small crown 8vo, 2s. cloth.

"Contains much valuable information for the class for whom it is intended, especially in the chapters on the management of boilers and engines."—*Nautical Magazine.*

"A useful introduction to the more elaborate text books."—*Scotsman.*

"To a student who has the requisite desire and resolve to attain a thorough knowledge, Mr. Brewer offers decidedly useful help."—*Athenæum.*

Navigation.

PRACTICAL NAVIGATION. Consisting of THE SAILOR'S SEA-BOOK, by JAMES GREENWOOD and W. H. ROSSER; together with the requisite Mathematical and Nautical Tables for the Working of the Problems, by HENRY LAW, C.E., and Professor J. R. YOUNG. Illustrated. 12mo, 7s. strongly half-bound.

MINING AND METALLURGY.

Metalliferous Mining in the United Kingdom.

BRITISH MINING: A Treatise on the History, Discovery, Practical Development, and Future Prospects of Metalliferous Mines in the United Kingdom. By Robert Hunt, F.R.S., Keeper of Mining Records; Editor of "Ure's Dictionary of Arts, Manufactures, and Mines," &c. Upwards of 950 pp., with 230 Illustrations. Second Edition, Revised. Super-royal 8vo, £2 2*s*. cloth.

"One of the most valuable works of reference of modern times. Mr. Hunt, as keeper of mining records of the United Kingdom, has had opportunities for such a task not enjoyed by anyone else, and has evidently made the most of them. . . . The language and style adopted are good, and the treatment of the various subjects laborious, conscientious, and scientific."—*Engineering.*

"The book is, in fact, a treasure-house of statistical information on mining subjects, and we know of no other work embodying so great a mass of matter of this kind. Were this the only merit of Mr. Hunt's volume, it would be sufficient to render it indispensable in this library of everyone interested in the development of the mining and metallurgical industries of this country." —*Athenæum.*

"A mass of information not elsewhere available, and of the greatest value to those who may be interested in our great mineral industries."—*Engineer.*

"A sound, business-like collection of interesting facts. . . . The amount of information Mr. Hunt has brought together is enormous. . . . The volume appears likely to convey more instruction upon the subject than any work hitherto published."—*Mining Journal.*

Colliery Management.

THE COLLIERY MANAGER'S HANDBOOK: A Comprehensive Treatise on the Laying-out and Working of Collieries, Designed as a Book of Reference for Colliery Managers, and for the Use of Coal-Mining Students preparing for First-class Certificates. By Caleb Pamely, Mining Engineer and Surveyor; Member of the North of England Institute of Mining and Mechanical Engineers; and Member of the South Wales Institute of Mining Engineers. With nearly 500 Plans, Diagrams, and other Illustrations. Medium 8vo, about 600 pages. Price £1 5*s*. strongly bound. [*Just ready.*

Coal and Iron.

THE COAL AND IRON INDUSTRIES OF THE UNITED KINGDOM. Comprising a Description of the Coal Fields, and of the Principal Seams of Coal, with Returns of their Produce and its Distribution, and Analyses of Special Varieties. Also an Account of the occurrence of Iron Ores in Veins or Seams; Analyses of each Variety; and a History of the Rise and Progress of Pig Iron Manufacture. By Richard Meade, Assistant Keeper of Mining Records. With Maps. 8vo, £1 8*s*. cloth.

"The book is one which must find a place on the shelves of all interested in coal and iron production, and in the iron, steel, and other metallurgical industries."—*Engineer.*

"Of this book we may unreservedly say that it is the best of its class which we have ever met. . . . A book of reference which no one engaged in the iron or coal trades should omit from his library."—*Iron and Coal Trades Review.*

Prospecting for Gold and other Metals.

THE PROSPECTOR'S HANDBOOK: A Guide for the Prospector and Traveller in Search of Metal-Bearing or other Valuable Minerals. By J. W. Anderson, M.A. (Camb.), F.R.G.S., Author of "Fiji and New Caledonia." Fifth Edition, thoroughly Revised and Enlarged. Small crown 8vo, 3*s*. 6*d*. cloth.

"Will supply a much felt want, especially among Colonists, in whose way are so often thrown many mineralogical specimens the value of which it is difficult to determine."—*Engineer.*

"How to find commercial minerals, and how to identify them when they are found, are the leading points to which attention is directed. The author has managed to pack as much practical detail into his pages as would supply material for a book three times its size."—*Mining Journal.*

Mining Notes and Formulæ.

NOTES AND FORMULÆ FOR MINING STUDENTS. By John Herman Merivale, M.A., Certificated Colliery Manager, Professor of Mining in the Durham College of Science, Newcastle-upon-Tyne. Third Edition, Revised and Enlarged. Small crown 8vo, 2*s*. 6*d*. cloth. [*Just published.*

"Invaluable to anyone who is working up for an examination on mining subjects."—*Coal and Iron Trades Review.*

"The author has done his work in an exceedingly creditable manner, and has produced a book that will be of service to students, and those who are practically engaged in mining operations."—*Engineer.*

"A vast amount of technical matter of the utmost value to mining engineers, and of considerable interest to students."—*Schoolmaster.*

Explosives.

A HANDBOOK ON MODERN EXPLOSIVES. Being a Practical Treatise on the Manufacture and Application of Dynamite, Gun-Cotton, Nitro-Glycerine and other Explosive Compounds. Including the Manufacture of Collodion-Cotton. By M. EISSLER, Mining Engineer and Metallurgical Chemist, Author of "The Metallurgy of Gold," "The Metallurgy of Silver," &c. With about 100 Illustrations. Crown 8vo, 10*s*. 6*d*. cloth. [*Just published.*

"Useful not only to the miner, but also to officers of both services to whom blasting and the use of explosives generally may at any time become a necessary auxiliary."—*Nature.*

"A veritable mine of information on the subject of explosives employed for military, mining and blasting purposes."—*Army and Navy Gazette.*

"The book is clearly written. Taken as a whole, we consider it an excellent little book and one that should be found of great service to miners and others who are engaged in work requiring the use of explosives."—*Athenæum.*

Gold, Metallurgy of.

THE METALLURGY OF GOLD: A Practical Treatise on the Metallurgical Treatment of Gold-bearing Ores. Including the Processes of Concentration and Chlorination, and the Assaying, Melting and Refining of Gold. By M. EISSLER, Mining Engineer and Metallurgical Chemist, formerly Assistant Assayer of the U. S. Mint, San Francisco. Third Edition, Revised and greatly Enlarged. With 187 Illustrations. Crown 8vo, 12*s*. 6*d*. cloth. [*Just published.*

"This book thoroughly deserves its title of a 'Practical Treatise.' The whole process of gold milling, from the breaking of the quartz to the assay of the bullion, is described in clear and orderly narrative and with much, but not too much, fulness of detail."—*Saturday Review.*

"The work is a storehouse of information and valuable data, and we strongly recommend it to all professional men engaged in the gold-mining industry."—*Mining Journal.*

Silver, Metallurgy of.

THE METALLURGY OF SILVER: A Practical Treatise on the Amalgamation, Roasting and Lixiviation of Silver Ores. Including the Assaying, Melting and Refining of Silver Bullion. By M. EISSLER, Author of "The Metallurgy of Gold." With 124 Illustrations. Crown 8vo, 10*s*. 6*d*. cloth.

"A practical treatise, and a technical work which we are convinced will supply a long-felt want amongst practical men, and at the same time be of value to students and others indirectly connected with the industries."—*Mining Journal.*

"From first to last the book is thoroughly sound and reliable."—*Colliery Guardian.*

"For chemists, practical miners, assayers and investors alike, we do not know of any work on the subject so handy and yet so comprehensive."—*Glasgow Herald.*

Silver-Lead, Metallurgy of.

THE METALLURGY OF ARGENTIFEROUS LEAD ORES: A Practical Treatise on the Smelting of Silver-Lead Ores and the Refining of Lead Bullion. Illustrated with Plans and Sections of Smelting Furnaces and Plant in Europe and America. By M. EISSLER, Author of "The Metallurgy of Gold," "The Metallurgy of Silver," &c. Cr. 8vo. [*In the press.*

Metalliferous Minerals and Mining.

TREATISE ON METALLIFEROUS MINERALS AND MINING. By D. C. DAVIES, F.G.S., Mining Engineer, &c., Author of "A Treatise on Slate and Slate Quarrying." Illustrated with numerous Wood Engravings. Fourth Edition, carefully Revised. Crown 8vo, 12*s*. 6*d*. cloth.

"Neither the practical miner nor the general reader interested in mines can have a better book for his companion and his guide."—*Mining Journal.*

"We are doing our readers a service in calling their attention to this valuable work."—*Mining World.*

"A book that will not only be useful to the geologist, the practical miner, and the metallurgist, but also very interesting to the general public."—*Iron.*

"As a history of the present state of mining throughout the world this book has a real value, and it supplies an actual want."—*Athenæum.*

Earthy Minerals and Mining.

A TREATISE ON EARTHY & OTHER MINERALS AND MINING. By D. C. DAVIES, F.G.S. Uniform with, and forming a Companion Volume to, the same Author's "Metalliferous Minerals and Mining." With 76 Wood Engravings. Second Edition. Crown 8vo, 12*s*. 6*d*. cloth.

"We do not remember to have met with any English work on mining matters that contains the same amount of information packed in equally convenient form."—*Academy.*

"We should be inclined to rank it as among the very best of the handy technical and trades manuals which have recently appeared."—*British Quarterly Review.*

Mineral Surveying and Valuing.

THE MINERAL SURVEYOR AND VALUER'S COMPLETE GUIDE, comprising a Treatise on Improved Mining Surveying and the Valuation of Mining Properties, with New Traverse Tables. By WM. LINTERN, Mining and Civil Engineer. Third Edition, with an Appendix on "Magnetic and Angular Surveying," with Records of the Peculiarities of Needle Disturbances. With Four Plates of Diagrams, Plans, &c. 12mo, 4*s.* cloth. [*Just published.*

"Mr. Lintern's book forms a valuable and thoroughly trustworthy guide."—*Iron and Coal Trades Review.*

"This new edition must be of the highest value to colliery surveyors, proprietors and managers."—*Colliery Guardian.*

Asbestos and its Uses.

ASBESTOS: Its Properties, Occurrence and Uses. With some Account of the Mines of Italy and Canada. By ROBERT H. JONES. With Eight Collotype Plates and other Illustrations. Crown 8vo, 12*s.* 6*d.* cloth. [*Just published.*

"An interesting and invaluable work."—*Colliery Guardian.*

"We counsel our readers to get this exceedingly interesting work for themselves; they will find in it much that is suggestive, and a great deal that is of immediate and practical usefulness."—*Builder.*

"A valuable addition to the architect's and engineer's library."—*Building News.*

Underground Pumping Machinery.

MINE DRAINAGE. Being a Complete and Practical Treatise on Direct-Acting Underground Steam Pumping Machinery, with a Description of a large number of the best known Engines, their General Utility and the Special Sphere of their Action, the Mode of their Application, and their merits compared with other forms of Pumping Machinery. By STEPHEN MICHELL. 8vo, 15*s.* cloth.

"Will be highly esteemed by colliery owners and lessees, mining engineers, and students generally who require to be acquainted with the best means of securing the drainage of mines. It is a most valuable work, and stands almost alone in the literature of steam pumping machinery."—*Colliery Guardian.*

"Much valuable information is given, so that the book is thoroughly worthy of an extensive circulation amongst practical men and purchasers of machinery."—*Mining Journal.*

Mining Tools.

A MANUAL OF MINING TOOLS. For the Use of Mine Managers, Agents, Students, &c. By WILLIAM MORGANS, Lecturer on Practical Mining at the Bristol School of Mines. 12mo, 2*s.* 6*d.* cloth limp.

ATLAS OF ENGRAVINGS to Illustrate the above, containing 235 Illustrations of Mining Tools, drawn to scale. 4to, 4*s.* 6*d.* cloth.

"Students in the science of mining, and overmen, captains, managers, and viewers may gain practical knowledge and useful hints by the study of Mr. Morgans' manual."—*Colliery Guardian.*

"A valuable work, which will tend materially to improve our mining literature."—*Mining Journal.*

Coal Mining.

COAL AND COAL MINING: A Rudimentary Treatise on. By the late Sir WARINGTON W. SMYTH, M.A., F.R.S., &c., Chief Inspector of the Mines of the Crown. Seventh Edition, Revised and Enlarged. With numerous Illustrations. 12mo, 4*s.* cloth boards. [*Just published.*

"As an outline is given of every known coal-field in this and other countries, as well as of the principal methods of working, the book will doubtless interest a very large number of readers."—*Mining Journal.*

Subterraneous Surveying.

SUBTERRANEOUS SURVEYING, Elementary and Practical Treatise on, with and without the Magnetic Needle. By THOMAS FENWICK, Surveyor of Mines, and THOMAS BAKER, C.E. Illust. 12mo, 3*s.* cloth boards.

Granite Quarrying.

GRANITES AND OUR GRANITE INDUSTRIES. By GEORGE F. HARRIS, F.G.S., Membre de la Société Belge de Géologie, Lecturer on Economic Geology at the Birkbeck Institution, &c. With Illustrations. Crown 8vo, 2*s.* 6*d.* cloth.

"A clearly and well-written manual for persons engaged or interested in the granite industry."—*Scotsman.*

"An interesting work, which will be deservedly esteemed."—*Colliery Guardian.*

"An exceedingly interesting and valuable monograph on a subject which has hitherto received unaccountably little attention in the shape of systematic literary treatment."—*Scottish Leader.*

ELECTRICITY, ELECTRICAL ENGINEERING, etc.

Electrical Engineering.

THE ELECTRICAL ENGINEER'S POCKET-BOOK OF MODERN RULES, FORMULÆ, TABLES AND DATA. By H. R. Kempe, M.Inst.E.E., A.M.Inst C.E., Technical Officer Postal Telegraphs, Author of "A Handbook of Electrical Testing," &c. With numerous Illustrations, royal 32mo, oblong, 5*s.* leather. [*Just published.*

"There is very little in the shape of formulæ or data which the electrician is likely to want in a hurry which cannot be found in its pages."—*Practical Engineer.*

"A very useful book of reference for daily use in practical electrical engineering and its various applications to the industries of the present day."—*Iron.*

"It is the best book of its kind."—*Electrical Engineer.*

"Well arranged and compact. The Electrical Engineer's Pocket-Book is a good one."—*Electrician.*

"Strongly recommended to those engaged in the various electrical industries."—*Electrical Review.*

Electric Lighting.

ELECTRIC LIGHT FITTING: A Handbook for Working Electrical Engineers, embodying Practical Notes on Installation Management. By John W. Urquhart, Electrician, Author of "Electric Light," &c. With numerous Illustrations, crown 8vo, 5*s.* cloth. [*Just published.*

"This volume deals with what may be termed the mechanics of electric lighting, and is addressed to men who are already engaged in the work or are training for it. The work traverses a great deal of ground, and may be read as a sequel to the same author's useful work on 'Electric Light.'"—*Electrician.*

"This is an attempt to state in the simplest language the precautions which should be adopted in installing the electric light, and to give information for the guidance of those who have to run the plant when installed. The book is well worth the perusal of the workmen for whom it is written."—*Electrical Review.*

"Eminently practical and useful. . . . Ought to be in the hands of everyone in charge of an electric light plant."—*Electrical Engineer.*

"Altogether Mr. Urquhart has succeeded in producing a really capital book, which we have no hesitation in recommending to the notice of working electricians and electrical engineers."—*Mechanical World.*

Electric Light.

ELECTRIC LIGHT: Its Production and Use. Embodying Plain Directions for the Treatment of Dynamo-Electric Machines, Batteries, Accumulators, and Electric Lamps. By J. W. Urquhart, C.E., Author of "Electric Light Fitting," "Electroplating," &c. Fourth Edition, carefully Revised, with Large Additions and 145 Illustrations. Crown 8vo, 7*s.* 6*d.* cloth. [*Just published.*

"The book is by far the best that we have yet met with on the subject."—*Athenæum.*

"It is the only work at present available which gives, in language intelligible for the most part to the ordinary reader, a general but concise history of the means which have been adopted up to the present time in producing the electric light."—*Metropolitan.*

"The book contains a general account of the means adopted in producing the electric light, not only as obtained from voltaic or galvanic batteries, but treats at length of the dynamo-electric machine in several of its forms."—*Colliery Guardian.*

Construction of Dynamos.

DYNAMO CONSTRUCTION: A Practical Handbook for the Use of Engineer Constructors and Electricians in Charge. With Examples of leading English, American and Continental Dynamos and Motors. By J. W. Urquhart, Author of "Electric Light," "Electric Light Fitting," &c. Crown 8vo. [*In the press.*

Text Book of Electricity.

THE STUDENT'S TEXT-BOOK OF ELECTRICITY. By Henry M. Noad, Ph.D., F.R.S., F.C.S. New Edition, carefully Revised. With an Introduction and Additional Chapters, by W. H. Preece, M.I.C.E., Vice-President of the Society of Telegraph Engineers, &c. With 470 Illustrations. Crown 8vo, 12*s.* 6*d.* cloth.

"The original plan of this book has been carefully adhered to so as to make it a reflex of the existing state of electrical science, adapted for students. . . . Discovery seems to have progressed with marvellous strides; nevertheless it has now apparently ceased, and practical applications have commenced their career; and it is to give a faithful account of these that this fresh edition of Dr. Noad's valuable text-book is launched forth."—*Extract from Introduction by W. H. Preece, Esq.*

"We can recommend Dr. Noad's book for clear style, great range of subject, a good index and a plethora of woodcuts. Such collections as the present are indispensable."—*Athenæum.*

"An admirable text book for every student — beginner or advanced — of electricity."—*Engineering.*

Electric Lighting.

THE ELEMENTARY PRINCIPLES OF ELECTRIC LIGHTING. By ALAN A. CAMPBELL SWINTON, Associate I.E.E. Second Edition, Enlarged and Revised. With 16 Illustrations. Crown 8vo, 1*s.* 6*d.* cloth.

"Anyone who desires a short and thoroughly clear exposition of the elementary principles of electric-lighting cannot do better than read this little work."—*Bradford Observer.*

Electricity.

A MANUAL OF ELECTRICITY: Including Galvanism, Magnetism, Dia-Magnetism, Electro-Dynamics, Magno-Electricity, and the Electric Telegraph. By HENRY M. NOAD, Ph.D., F.R.S., F.C.S. Fourth Edition. With 500 Woodcuts. 8vo, £1 4*s.* cloth.

"It is worthy of a place in the library of every public institution."—*Mining Journal.*

Dynamo Construction.

HOW TO MAKE A DYNAMO: A Practical Treatise for Amateurs. Containing numerous Illustrations and Detailed Instructions for Constructing a Small Dynamo, to Produce the Electric Light. By ALFRED CROFTS. Third Edition, Revised and Enlarged. Crown 8vo, 2*s.* cloth. [*Just published.*

"The instructions given in this unpretentious little book are sufficiently clear and explicit to enable any amateur mechanic possessed of average skill and the usual tools to be found in an amateur's workshop, to build a practical dynamo machine."—*Electrician.*

NATURAL SCIENCE, etc.

Pneumatics and Acoustics.

PNEUMATICS: including Acoustics and the Phenomena of Wind Currents, for the Use of Beginners. By CHARLES TOMLINSON, F.R.S., F.C.S., &c. Fourth Edition, Enlarged. With numerous Illustrations. 12mo, 1*s.* 6*d.* cloth.

"Beginners in the study of this important application of science could not have a better manual."—*Scotsman.*

"A valuable and suitable text-book for students of Acoustics and the Phenomena of Wind Currents."—*Schoolmaster.*

Conchology.

A MANUAL OF THE MOLLUSCA: Being a Treatise on Recent and Fossil Shells. By S. P. WOODWARD, A.L.S., F.G.S., late Assistant Palæontologist in the British Museum. With an Appendix on *Recent and Fossil Conchological Discoveries,* by RALPH TATE, A.L.S., F.G.S. Illustrated by A. N. WATERHOUSE and JOSEPH WILSON LOWRY. With 23 Plates and upwards of 300 Woodcuts. Reprint of Fourth Ed., 1880. Cr. 8vo, 7*s.* 6*d.* cl.

"A most valuable storehouse of conchological and geological information."—*Science Gossip.*

Geology.

RUDIMENTARY TREATISE ON GEOLOGY, PHYSICAL AND HISTORICAL. Consisting of "Physical Geology," which sets forth the leading Principles of the Science; and "Historical Geology," which treats of the Mineral and Organic Conditions of the Earth at each successive epoch, especial reference being made to the British Series of Rocks. By RALPH TATE, A.L.S., F.G.S., &c. &c. With 250 Illustrations. 12mo, 5*s.* cloth boards.

"The fulness of the matter has elevated the book into a manual. Its information is exhaustive and well arranged."—*School Board Chronicle.*

Geology and Genesis.

THE TWIN RECORDS OF CREATION; or, Geology and Genesis: their Perfect Harmony and Wonderful Concord. By GEORGE W. VICTOR LE VAUX. Numerous Illustrations. Fcap. 8vo, 5*s.* cloth.

"A valuable contribution to the evidences of Revelation, and disposes very conclusively of the arguments of those who would set God's Works against God's Word. No real difficulty is shirked, and no sophistry is left unexposed."—*The Rock.*

"The remarkable peculiarity of this author is that he combines an unbounded admiration of science with an unbounded admiration of the Written record. The two impulses are balanced to a nicety; and the consequence is that difficulties, which to minds less evenly poised would be serious, find immediate solutions of the happiest kinds."—*London Review.*

Astronomy.

ASTRONOMY. By the late Rev. ROBERT MAIN, M.A., F.R.S., formerly Radcliffe Observer at Oxford. Third Edition, Revised and Corrected to the present time, by WILLIAM THYNNE LYNN, B.A., F.R.A.S., formerly of the Royal Observatory, Greenwich. 12mo, 2*s.* cloth limp.

"A sound and simple treatise, very carefully edited, and a capital book for beginners."—*Knowledge.*

"Accurately brought down to the requirements of the present time by Mr. Lynn."—*Educational Times.*

DR. LARDNER'S COURSE OF NATURAL PHILOSOPHY.

THE HANDBOOK OF MECHANICS. Enlarged and almost re-written by Benjamin Loewy, F.R.A.S. With 378 Illustrations. Post 8vo, 6s. cloth.

"The perspicuity of the original has been retained, and chapters which had become obsolete have been replaced by others of more modern character. The explanations throughout are studiously popular, and care has been taken to show the application of the various branches of physics to the industrial arts, and to the practical business of life."—*Mining Journal.*

"Mr. Loewy has carefully revised the book, and brought it up to modern requirements."—*Nature.*

"Natural philosophy has had few exponents more able or better skilled in the art of popularising the subject than Dr. Lardner; and Mr. Loewy is doing good service in fitting this treatise, and the others of the series, for use at the present time."—*Scotsman.*

THE HANDBOOK OF HYDROSTATICS AND PNEUMATICS. New Edition, Revised and Enlarged, by Benjamin Loewy, F.R.A.S. With 236 Illustrations. Post 8vo, 5s. cloth.

"For those 'who desire to attain an accurate knowledge of physical science without the profound methods of mathematical investigation,' this work is not merely intended, but well adapted." —*Chemical News.*

"The volume before us has been carefully edited, augmented to nearly twice the bulk of the former edition, and all the most recent matter has been added. . . . It is a valuable text-book." —*Nature.*

"Candidates for pass examinations will find it, we think, specially suited to their requirements." *English Mechanic.*

THE HANDBOOK OF HEAT. Edited and almost entirely re-written by Benjamin Loewy, F.R.A.S., &c. 117 Illustrations. Post 8vo, 6s. cloth.

"The style is always clear and precise, and conveys instruction without leaving any cloudiness or lurking doubts behind."—*Engineering.*

"A most exhaustive book on the subject on which it treats, and is so arranged that it can be understood by all who desire to attain an accurate knowledge of physical science. . . . . Mr. Loewy has included all the latest discoveries in the varied laws and effects of heat."—*Standard.*

"A complete and handy text-book for the use of students and general readers."—*English Mechanic.*

THE HANDBOOK OF OPTICS. By Dionysius Lardner, D.C.L., formerly Professor of Natural Philosophy and Astronomy in University College, London. New Edition. Edited by T. Olver Harding, B.A. Lond., of University College, London. With 298 Illustrations. Small 8vo, 448 pages, 5s. cloth.

"Written by one of the ablest English scientific writers, beautifully and elaborately illustrated." *Mechanic's Magazine.*

THE HANDBOOK OF ELECTRICITY, MAGNETISM, AND ACOUSTICS. By Dr. Lardner. Ninth Thousand. Edit. by George Carey Foster, B.A., F.C.S. With 400 Illustrations. Small 8vo, 5s. cloth.

"The book could not have been entrusted to anyone better calculated to preserve the terse and lucid style of Lardner, while correcting his errors and bringing up his work to the present state of scientific knowledge."—*Popular Science Review.*

THE HANDBOOK OF ASTRONOMY. Forming a Companion to the "Handbook of Natural Philosophy." By Dionysius Lardner, D.C.L., formerly Professor of Natural Philosophy and Astronomy in University College, London. Fourth Edition. Revised and Edited by Edwin Dunkin, F.R.A.S., Royal Observatory, Greenwich. With 38 Plates and upwards of 100 Woodcuts. In One Vol., small 8vo, 550 pages, 9s. 6*d*. cloth.

"Probably no other book contains the same amount of information in so compendious and well-arranged a form—certainly none at the price at which this is offered to the public."—*Athenæum.*

"We can do no other than pronounce this work a most valuable manual of astronomy, and we strongly recommend it to all who wish to acquire a general—but at the same time correct—acquaintance with this sublime science."—*Quarterly Journal of Science.*

"One of the most deservedly popular books on the subject . . . We would recommend not only the student of the elementary principles of the science, but he who aims at mastering the higher and mathematical branches of astronomy, not to be without this work beside him."—*Practical Magazine.*

Dr. Lardner's Electric Telegraph.

THE ELECTRIC TELEGRAPH. By Dr. Lardner. Revised and Re-written by E. B. Bright, F.R.A.S. 140 Illustrations. Small 8vo, 2s. 6*d*. cloth.

"One of the most readable books extant on the Electric Telegraph."—*English Mechanic.*

DR. LARDNER'S MUSEUM OF SCIENCE AND ART.

THE MUSEUM OF SCIENCE AND ART. Edited by DIONYSIUS LARDNER, D.C.L., formerly Professor of Natural Philosophy and Astronomy in University College, London. With upwards of 1,200 Engravings on Wood. In 6 Double Volumes, £1 1s., in a new and elegant cloth binding; or handsomely bound in half-morocco, 31s. 6d.

*** OPINIONS OF THE PRESS.

"This series, besides affording popular but sound instruction on scientific subjects, with which the humblest man in the country ought to be acquainted, also undertakes that teaching of 'Common Things' which every well-wisher of his kind is anxious to promote. Many thousand copies of this serviceable publication have been printed, in the belief and hope that the desire for instruction and improvement widely prevails; and we have no fear that such enlightened faith will meet with disappointment."—*Times.*

"A cheap and interesting publication, alike informing and attractive. The papers combine subjects of importance and great scientific knowledge, considerable inductive powers, and a popular style of treatment."—*Spectator.*

"The 'Museum of Science and Art' is the most valuable contribution that has ever been made to the Scientific Instruction of every class of society."—Sir DAVID BREWSTER, in the *North British Review.*

"Whether we consider the liberality and beauty of the illustrations, the charm of the writing, or the durable interest of the matter, we must express our belief that there is hardly to be found among the new books one that would be welcomed by people of so many ages and classes as a valuable present."—*Examiner.*

**** Separate books formed from the above, suitable for Workmen's Libraries, Science Classes, etc.*

Common Things Explained. Containing Air, Earth, Fire, Water, Time, Man, the Eye, Locomotion, Colour, Clocks and Watches, &c. 233 Illustrations, cloth gilt, 5s.

The Microscope. Containing Optical Images, Magnifying Glasses, Origin and Description of the Microscope, Microscopic Objects, the Solar Microscope, Microscopic Drawing and Engraving, &c. 147 Illustrations, cloth gilt, 2s.

Popular Geology. Containing Earthquakes and Volcanoes, the Crust of the Earth, &c. 201 Illustrations, cloth gilt, 2s. 6d.

Popular Physics. Containing Magnitude and Minuteness, the Atmosphere, Meteoric Stones, Popular Fallacies, Weather Prognostics, the Thermometer, the Barometer, Sound, &c. 85 Illustrations, cloth gilt, 2s. 6d.

Steam and its Uses. Including the Steam Engine, the Locomotive, and Steam Navigation 89 Illustrations, cloth gilt, 2s.

Popular Astronomy. Containing How to observe the Heavens—The Earth, Sun, Moon, Planets, Light, Comets, Eclipses, Astronomical Influences, &c. 182 Illustrations, 4s. 6d.

The Bee and White Ants: Their Manners and Habits. With Illustrations of Animal Instinct and Intelligence. 135 Illustrations, cloth gilt, 2s.

The Electric Telegraph Popularized. To render intelligible to all who can Read, irrespective of any previous Scientific Acquirements, the various forms of Telegraphy in Actual Operation. 100 Illustrations, cloth gilt, 1s. 6d.

Dr. Lardner's School Handbooks.

NATURAL PHILOSOPHY FOR SCHOOLS. By Dr. LARDNER. 328 Illustrations. Sixth Edition. One Vol., 3s. 6d. cloth.

"A very convenient class-book for junior students in private schools. It is intended to convey, in clear and precise terms, general notions of all the principal divisions of Physical Science."—*British Quarterly Review.*

ANIMAL PHYSIOLOGY FOR SCHOOLS. By Dr. LARDNER. With 190 Illustrations. Second Edition. One Vol., 3s. 6d. cloth.

"Clearly written, well arranged, and excellently illustrated."—*Gardener's Chronicle.*

COUNTING-HOUSE WORK, TABLES, etc.

Accounts for Manufacturers.

FACTORY ACCOUNTS: Their Principles and Practice. A Handbook for Accountants and Manufacturers, with Appendices on the Nomenclature of Machine Details; the Income Tax Acts; the Rating of Factories; Fire and Boiler Insurance; the Factory and Workshop Acts, &c., including also a Glossary of Terms and a large number of Specimen Rulings. By EMILE GARCKE and J. M. FELLS. Third Edition. Demy 8vo, 250 pages, price 6*s.* strongly bound.

"A very interesting description of the requirements of Factory Accounts. . . . the principle of assimilating the Factory Accounts to the general commercial books is one which we thoroughly agree with."—*Accountants' Journal.*

"Characterised by extreme thoroughness. There are few owners of Factories who would not derive great benefit from the perusal of this most admirable work."—*Local Government Chronicle.*

Foreign Commercial Correspondence.

THE FOREIGN COMMERCIAL CORRESPONDENT: Being Aids to Commercial Correspondence in Five Languages—English, French, German, Italian and Spanish. By CONRAD E. BAKER. Second Edition, Revised. Crown 8vo, 3*s.* 6d. cloth.

"Whoever wishes to correspond in all the languages mentioned by Mr. Baker cannot do better than study this work, the materials of which are excellent and conveniently arranged. They consist not of entire specimen letters, but what are far more useful—short passages, sentences, or phrases expressing the same general idea in various forms."—*Athenæum.*

"A careful examination has convinced us that it is unusually complete, well arranged and reliable. The book is a thoroughly good one."—*Schoolmaster.*

Intuitive Calculations.

THE COMPENDIOUS CALCULATOR; or, Easy and Concise Methods of Performing the various Arithmetical Operations required in Commercial and Business Transactions, together with Useful Tables. By DANIEL O'GORMAN. Corrected and Extended by J. R. YOUNG, formerly Professor of Mathematics at Belfast College. Twenty-seventh Edition, carefully Revised by C. NORRIS. Fcap. 8vo, 2*s.* 6*d.* cloth limp; or, 3*s.* 6*d.* strongly half-bound in leather.

"It would be difficult to exaggerate the usefulness of a book like this to everyone engaged in commerce or manufacturing industry. It is crammed full of rules and formulæ for shortening and employing calculations."—*Knowledge.*

"Supplies special and rapid methods for all kinds of calculations. Of great utility to persons engaged in any kind of commercial transactions."—*Scotsman.*

Modern Metrical Units and Systems.

MODERN METROLOGY: A Manual of the Metrical Units and Systems of the Present Century. With an Appendix containing a proposed English System. By LOWIS D'A. JACKSON, A.M.Inst.C.E., Author of "Aid to Survey Practice," &c. Large crown 8vo, 12*s.* 6*d.* cloth.

"The author has brought together much valuable and interesting information. . . . We cannot but recommend the work to the consideration of all interested in the practical reform of our weights and measures."—*Nature.*

"For exhaustive tables of equivalent weights and measures of all sorts, and for clear demonstrations of the effects of the various systems that have been proposed or adopted, Mr. Jackson's treatise is without a rival."—*Academy.*

The Metric System and the British Standards.

A SERIES OF METRIC TABLES, in which the British Standard Measures and Weights are compared with those of the Metric System at present in Use on the Continent. By C. H. DOWLING, C.E. 8vo, 10*s.* 6*d.* strongly bound.

"Their accuracy has been certified by Professor Airy, the Astronomer-Royal."—*Builder.*

"Mr. Dowling's Tables are well put together as a ready-reckoner for the conversion of one system into the other."—*Athenæum.*

Iron and Metal Trades' Calculator.

THE IRON AND METAL TRADES' COMPANION. For expeditiously ascertaining the Value of any Goods bought or sold by Weight, from 1*s.* per cwt. to 112*s.* per cwt., and from one farthing per pound to one shilling per pound. Each Table extends from one pound to 100 tons. To which are appended Rules on Decimals, Square and Cube Root, Mensuration of Superficies and Solids, &c.; also Tables of Weights of Materials, and other Useful Memoranda. By THOS. DOWNIE. Strongly bound in leather, 396 pp., 9*s.*

"A most useful set of tables, and will supply a want, for nothing like them before existed."—*Building News.*

"Although specially adapted to the iron and metal trades, the tables will be found useful in every other business in which merchandise is bought and sold by weight."—*Railway News*

Calculator for Numbers and Weights Combined.

THE NUMBER, WEIGHT AND FRACTIONAL CALCULATOR. Containing upwards of 250,000 Separate Calculations, showing at a glance the value at 422 different rates, ranging from $\frac{1}{128}$th of a Penny to 20s. each, or per cwt., and £20 per ton, of any number of articles consecutively, from 1 to 470.—Any number of cwts., qrs., and lbs., from 1 cwt. to 470 cwts.—Any number of tons, cwts., qrs., and lbs., from 1 to 1,000 tons. By WILLIAM CHADWICK, Public Accountant. Third Edition, Revised and Improved. 8vo, price 18*s*., strongly bound for Office wear and tear. [*Just published.*

*** *This work is specially adapted for the Apportionment of Mileage Charges for Railway Traffic.*

☞ *This comprehensive and entirely unique and original Calculator is adapted for the use of Accountants and Auditors, Railway Companies, Canal Companies, Shippers, Shipping Agents, General Carriers, etc.*

Ironfounders, Brassfounders, Metal Merchants, Iron Manufacturers, Ironmongers, Engineers, Machinists, Boiler Makers, Millwrights, Roofing, Bridge and Girder Makers, Colliery Proprietors, etc.

Timber Merchants, Builders, Contractors, Architects, Surveyors, Auctioneers Valuers, Brokers, Mill Owners and Manufacturers, Mill Furnishers, Merchants and General Wholesale Tradesmen.

*** OPINIONS OF THE PRESS.

"The book contains the answers to questions, and not simply a set of ingenious puzzle methods of arriving at results. It is as easy of reference for any answer or any number of answers as a dictionary, and the references are even more quickly made. For making up accounts or estimates, the book must prove invaluable to all who have any considerable quantity of calculations involving price and measure in any combination to do."—*Engineer.*

"The most perfect work of the kind yet prepared."—*Glasgow Herald.*

Comprehensive Weight Calculator.

THE WEIGHT CALCULATOR. Being a Series of Tables upon a New and Comprehensive Plan, exhibiting at One Reference the exact Value of any Weight from 1 lb. to 15 tons, at 300 Progressive Rates, from 1*d*. to 168*s*. per cwt., and containing 186,000 Direct Answers, which, with their Combinations, consisting of a single addition (mostly to be performed at sight), will afford an aggregate of 10,266,000 Answers; the whole being calculated and designed to ensure correctness and promote despatch. By HENRY HARBEN, Accountant. Fourth Edition, carefully Corrected. Royal 8vo, strongly half-bound, £1 5*s*.

"A practical and useful work of reference for men of business generally; it is the best of the kind we have seen.'—*Ironmonger.*

"Of priceless value to business men. It is a necessary book in all mercantile offices."—*Sheffield Independent.*

Comprehensive Discount Guide.

THE DISCOUNT GUIDE. Comprising several Series of Tables for the use of Merchants, Manufacturers, Ironmongers, and others, by which may be ascertained the exact Profit arising from any mode of using Discounts, either in the Purchase or Sale of Goods, and the method of either Altering a Rate of Discount or Advancing a Price, so as to produce, by one operation, a sum that will realise any required profit after allowing one or more Discounts: to which are added Tables of Profit or Advance from 1¼ to 90 per cent., Tables of Discount from 1¼ to 98¾ per cent., and Tables of Commission, &c., from ⅛ to 10 per cent. By HENRY HARBEN, Accountant, Author of "The Weight Calculator." New Edition, carefully Revised and Corrected. Demy 8vo, 544 pp. half-bound, £1 5*s*.

"A book such as this can only be appreciated by business men, to whom the saving of time means saving of money. We have the high authority of Professor J. R. Young that the tables throughout the work are constructed upon strictly accurate principles. The work is a model of typographical clearness, and must prove of great value to merchants, manufacturers, and general traders."—*British Trade Journal.*

Iron Shipbuilders' and Merchants' Weight Tables.

IRON-PLATE WEIGHT TABLES: For Iron Shipbuilders, Engineers and Iron Merchants. Containing the Calculated Weights of upwards of 150,000 different sizes of Iron Plates, from 1 foot by 6 in. by ¼ in. to 10 feet by 5 feet by 1 in. Worked out on the basis of 40 lbs. to the square foot of Iron of 1 inch in thickness. Carefully compiled and thoroughly Revised by H. BURLINSON and W. H. SIMPSON. Oblong 4to, 25*s*. half-bound.

"This work will be found of great utility. The authors have had much practical experience of what is wanting in making estimates; and the use of the book will save much time in making elaborate calculations."—*English Mechanic*

INDUSTRIAL AND USEFUL ARTS.

Soap-making.

THE ART OF SOAP-MAKING: A Practical Handbook of the Manufacture of Hard and Soft Soaps, Toilet Soaps, etc. Including many New Processes, and a Chapter on the Recovery of Glycerine from Waste Leys. By ALEXANDER WATT, Author of "Electro-Metallurgy Practically Treated," &c. With numerous Illustrations. Fourth Edition, Revised and Enlarged. Crown 8vo, 7*s.* 6*d.* cloth. [*Just published.*

"The work will prove very useful, not merely to the technological student, but to the practical soap-boiler who wishes to understand the theory of his art."—*Chemical News.*

"Mr. Watt's book is a thoroughly practical treatise on an art which has almost no literature in our language. We congratulate the author on the success of his endeavour to fill a void in English technical literature."—*Nature.*

Paper Making.

THE ART OF PAPER MAKING: A Practical Handbook of the Manufacture of Paper from Rags, Esparto, Straw and other Fibrous Materials, Including the Manufacture of Pulp from Wood Fibre, with a Description of the Machinery and Appliances used. To which are added Details of Processes for Recovering Soda from Waste Liquors. By ALEXANDER WATT. With Illustrations. Crown 8vo, 7*s.* 6*d.* cloth. [*Just published.*

"This book is succinct, lucid, thoroughly practical, and includes everything of interest to the modern paper maker. It is the latest, most practical and most complete work on the paper-making art before the British public."—*Paper Record.*

"It may be regarded as the standard work on the subject. The book is full of valuable information. The 'Art of Paper-making,' is in every respect a model of a text-book, either for a technical class or for the private student."—*Paper and Printing Trades Journal.*

"Admirably adapted for general as well as ordinary technical reference, and as a handbook for students in technical education may be warmly commended."—*The Paper Maker's Monthly Journal.*

Leather Manufacture.

THE ART OF LEATHER MANUFACTURE. Being a Practical Handbook, in which the Operations of Tanning, Currying, and Leather Dressing are fully Described, the Principles of Tanning Explained and many Recent Processes introduced. By ALEXANDER WATT, Author of "Soap-Making," &c. With numerous Illustrations. Second Edition. Crown 8vo, 9*s.* cloth.

"A sound, comprehensive treatise on tanning and its accessories. This book is an eminently valuable production, which redounds to the credit of both author and publishers."—*Chemical Review.*

"This volume is technical without being tedious, comprehensive and complete without being prosy, and it bears on every page the impress of a master hand. We have never come across a better trade treatise, nor one that so thoroughly supplied an absolute want."—*Shoe and Leather Trades' Chronicle.*

Boot and Shoe Making.

THE ART OF BOOT AND SHOE-MAKING. A Practical Handbook, including Measurement, Last-Fitting, Cutting-Out, Closing and Making, with a Description of the most approved Machinery employed. By JOHN B. LENO, late Editor of *St. Crispin*, and *The Boot and Shoe-Maker.* With numerous Illustrations. Third Edition. 12mo, 2*s.* cloth limp.

"This excellent treatise is by far the best work ever written on the subject. A new work, embracing all modern improvements, was much wanted. This want is now satisfied. The chapter on clicking, which shows how waste may be prevented, will save fifty times the price of the book." —*Scottish Leather Trader.*

Dentistry.

MECHANICAL DENTISTRY: A Practical Treatise on the Construction of the various kinds of Artificial Dentures. Comprising also Useful Formulæ, Tables and Receipts for Gold Plate, Clasps, Solders, &c. &c. By CHARLES HUNTER. Third Edition, Revised. With upwards of 100 Wood Engravings. Crown 8vo, 3*s.* 6*d.* cloth.

"The work is very practical."—*Monthly Review of Dental Surgery.*

"We can strongly recommend Mr. Hunter's treatise to all students preparing for the profession of dentistry, as well as to every mechanical dentist."—*Dublin Journal of Medical Science.*

Wood Engraving.

WOOD ENGRAVING: A Practical and Easy Introduction to the Study of the Art. By WILLIAM NORMAN BROWN. Second Edition. With numerous Illustrations. 12mo, 1*s.* 6*d.* cloth limp.

"The book is clear and complete, and will be useful to anyone wanting to understand the first elements of the beautiful art of wood engraving."—*Graphic.*

HANDYBOOKS FOR HANDICRAFTS. By PAUL N. HASLUCK.

Metal Turning.

THE METAL TURNER'S HANDYBOOK. A Practical Manual for Workers at the Foot-Lathe: Embracing Information on the Tools, Appliances and Processes employed in Metal Turning. By PAUL N. HASLUCK, Author of "Lathe-Work." With upwards of One Hundred Illustrations. Second Edition, Revised. Crown 8vo, 2*s.* cloth.

"Clearly and concisely written, excellent in every way."—*Mechanical World.*

Wood Turning.

THE WOOD TURNER'S HANDYBOOK. A Practical Manual for Workers at the Lathe: Embracing Information on the Tools, Appliances and Processes Employed in Wood Turning. By PAUL N. HASLUCK. With upwards of One Hundred Illustrations. Crown 8vo, 2*s.* cloth.

"We recommend the book to young turners and amateurs. A multitude of workmen have hitherto sought in vain for a manual of this special industry."—*Mechanical World.*

WOOD AND METAL TURNING. By P. N. HASLUCK. (Being the Two preceding Vols. bound together.) 300 pp., with upwards of 200 Illustrations, crown 8vo, 3*s.* 6*d.* cloth.

Watch Repairing.

THE WATCH JOBBER'S HANDYBOOK. A Practical Manual on Cleaning, Repairing and Adjusting. Embracing Information on the Tools, Materials, Appliances and Processes Employed in Watchwork. By PAUL N. HASLUCK. With upwards of One Hundred Illustrations. Cr. 8vo, 2*s.* cloth.

"All young persons connected with the trade should acquire and study this excellent, and at the same time, inexpensive work."—*Clerkenwell Chronicle.*

Clock Repairing.

THE CLOCK JOBBER'S HANDYBOOK: A Practical Manual on Cleaning, Repairing and Adjusting. Embracing Information on the Tools, Materials, Appliances and Processes Employed in Clockwork. By PAUL N. HASLUCK. With upwards of 100 Illustrations. Cr. 8vo, 2*s.* cloth.

"Of inestimable service to those commencing the trade."—*Coventry Standard.*

WATCH AND CLOCK JOBBING. By P. N. HASLUCK. (Being the Two preceding Vols. bound together.) 320 pp., with upwards of 200 Illustrations, crown 8vo, 3*s.* 6*d.* cloth.

Pattern Making.

THE PATTERN MAKER'S HANDYBOOK. A Practical Manual, embracing Information on the Tools, Materials and Appliances employed in Constructing Patterns for Founders. By PAUL N. HASLUCK. With One Hundred Illustrations. Crown 8vo, 2*s.* cloth.

"This handy volume contains sound information of considerable value to students and artificers."—*Hardware Trades Journal.*

Mechanical Manipulation.

THE MECHANIC'S WORKSHOP HANDYBOOK. A Practical Manual on Mechanical Manipulation. Embracing Information on various Handicraft Processes, with Useful Notes and Miscellaneous Memoranda. By PAUL N. HASLUCK. Crown 8vo, 2*s.* cloth.

"It is a book which should be found in every workshop, as it is one which will be continually referred to for a very great amount of standard information."—*Saturday Review.*

Model Engineering.

THE MODEL ENGINEER'S HANDYBOOK: A Practical Manual on Model Steam Engines. Embracing Information on the Tools, Materials and Processes Employed in their Construction. By PAUL N. HASLUCK. With upwards of 100 Illustrations. Crown 8vo, 2*s.* cloth.

"By carefully going through the work, amateurs may pick up an excellent notion of the construction of full-sized steam engines."—*Telegraphic Journal.*

Cabinet Making.

THE CABINET WORKER'S HANDYBOOK: A Practical Manual, embracing Information on the Tools, Materials, Appliances and Processes employed in Cabinet Work. By PAUL N. HASLUCK, Author of "Lathe Work," &c. With upwards of 100 Illustrations. Crown 8vo, 2*s.* cloth. [*Just published.*

"Thoroughly practical throughout. The amateur worker in wood will find it most useful."—*Glasgow Herald.*

Electrolysis of Gold, Silver, Copper, etc.

ELECTRO-DEPOSITION: A Practical Treatise on the Electrolysis of Gold, Silver, Copper, Nickel, and other Metals and Alloys. With descriptions of Voltaic Batteries, Magneto and Dynamo-Electric Machines, Thermopiles, and of the Materials and Processes used in every Department of the Art, and several Chapters on Electro-Metallurgy. By ALEXANDER WATT. Third Edition, Revised and Corrected. Crown 8vo, 9*s.* cloth.

"Eminently a book for the practical worker in electro-deposition. It contains practical descriptions of methods, processes and materials as actually pursued and used in the workshop."—*Engineer.*

Electro-Metallurgy.

ELECTRO-METALLURGY; Practically Treated. By ALEXANDER WATT, Author of "Electro-Deposition," &c. Ninth Edition, Enlarged and Revised, with Additional Illustrations, and including the most recent Processes. 12mo, 4*s.* cloth boards.

"From this book both amateur and artisan may learn everything necessary for the successful prosecution of electroplating."—*Iron.*

Electroplating.

ELECTROPLATING: A Practical Handbook on the Deposition of Copper, Silver, Nickel, Gold, Aluminium, Brass, Platinum, &c. &c. With Descriptions of the Chemicals, Materials, Batteries and Dynamo Machines used in the Art. By J. W. URQUHART, C.E. Second Edition, with Additions. Numerous Illustrations. Crown 8vo, 5*s.* cloth.

"An excellent practical manual."—*Engineering.*

"An excellent work, giving the newest information."—*Horological Journal.*

Electrotyping.

ELECTROTYPING: The Reproduction and Multiplication of Printing Surfaces and Works of Art by the Electro-deposition of Metals. By J. W. URQUHART, C.E. Crown 8vo, 5*s.* cloth.

"The book is thoroughly practical. The reader is, therefore, conducted through the leading laws of electricity, then through the metals used by electrotypers, the apparatus, and the depositing processes, up to the final preparation of the work."—*Art Journal.*

Horology.

A TREATISE ON MODERN HOROLOGY, in Theory and Practice. Translated from the French of CLAUDIUS SAUNIER, by JULIEN TRIPPLIN, F.R.A.S., and EDWARD RIGG, M.A., Assayer in the Royal Mint. With 78 Woodcuts and 22 Coloured Plates. Second Edition. Royal 8vo, £2 2*s.* cloth; £2 10*s.* half-calf.

"There is no horological work in the English language at all to be compared to this production of M. Saunier's for clearness and completeness. It is alike good as a guide for the student and as a reference for the experienced horologist and skilled workman."—*Horological Journal.*

"The latest, the most complete, and the most reliable of those literary productions to which continental watchmakers are indebted for the mechanical superiority over their English brethren—in fact, the Book of Books, is M. Saunier's 'Treatise.'"—*Watchmaker, Jeweller and Silversmith.*

Watchmaking.

THE WATCHMAKER'S HANDBOOK. A Workshop Companion for those engaged in Watchmaking and the Allied Mechanical Arts. From the French of CLAUDIUS SAUNIER. Enlarged by JULIEN TRIPPLIN, F.R.A.S., and EDWARD RIGG, M.A., Assayer in the Royal Mint. Woodcuts and Copper Plates. Third Edition, Revised. Crown 8vo, 9*s.* cloth.

"Each part is truly a treatise in itself. The arrangement is good and the language is clear and concise. It is an admirable guide for the young watchmaker."—*Engineering.*

"It is impossible to speak too highly of its excellence. It fulfils every requirement in a handbook intended for the use of a workman."—*Watch and Clockmaker.*

"This book contains an immense number of practical details bearing on the daily occupation of a watchmaker."—*Watchmaker and Metalworker* (Chicago).

Goldsmiths' Work.

THE GOLDSMITH'S HANDBOOK. By GEORGE E. GEE, Jeweller, &c. Third Edition, considerably Enlarged. 12mo, 3*s.* 6*d.* cl. bds.

"A good, sound educator, and will be accepted as an authority."—*Horological Journal.*

Silversmiths' Work.

THE SILVERSMITH'S HANDBOOK. By GEORGE E. GEE, Jeweller, &c. Second Edition, Revised, with numerous Illustrations. 12mo, 3*s.* 6*d.* cloth boards.

"Workers in the trade will speedily discover its merits when they sit down to study it."—*English Mechanic.*

⁂ *The above two works together, strongly half-bound, price 7s.*

Bread and Biscuit Baking.

THE BREAD AND BISCUIT BAKER'S AND SUGAR-BOILER'S ASSISTANT. Including a large variety of Modern Recipes. With Remarks on the Art of Bread-making. By ROBERT WELLS, Practical Baker. Second Edition, with Additional Recipes. Crown 8vo, 2*s.* cloth. [*Just published.*

"A large number of wrinkles for the ordinary cook, as well as the baker."—*Saturday Review.*

Confectionery.

THE PASTRYCOOK AND CONFECTIONER'S GUIDE. For Hotels, Restaurants and the Trade in general, adapted also for Family Use. By ROBERT WELLS, Author of "The Bread and Biscuit Baker's and Sugar Boiler's Assistant." Crown 8vo, 2*s.* cloth. [*Just published.*

"We cannot speak too highly of this really excellent work. In these days of keen competition our readers cannot do better than purchase this book."—*Bakers' Times.*

Ornamental Confectionery.

ORNAMENTAL CONFECTIONERY: A Guide for Bakers, Confectioners and Pastrycooks; including a variety of Modern Recipes, and Remarks on Decorative and Coloured Work. With 129 Original Designs. By ROBERT WELLS. Crown 8vo, 5*s.* cloth.

"A valuable work, practical, and should be in the hands of every baker and confectioner. The illustrative designs are alone worth treble the amount charged for the whole work."—*Bakers' Times.*

Flour Confectionery.

THE MODERN FLOUR CONFECTIONER. Wholesale and Retail. Containing a large Collection of Recipes for Cheap Cakes, Biscuits, &c. With Remarks on the Ingredients used in their Manufacture, &c. By R. WELLS, Author of "Ornamental Confectionery," "The Bread and Biscuit Baker," "The Pastrycook's Guide," &c. Crown 8vo, 2*s.* cloth. [*Just published.*

Laundry Work.

LAUNDRY MANAGEMENT. A Handbook for Use in Private and Public Laundries, Including Descriptive Accounts of Modern Machinery and Appliances for Laundry Work. By the EDITOR of "The Laundry Journal." With numerous Illustrations. Crown 8vo, 2*s.* 6*d.* cloth.

CHEMICAL MANUFACTURES & COMMERCE.

Alkali Trade, Manufacture of Sulphuric Acid, etc.

A MANUAL OF THE ALKALI TRADE, including the Manufacture of Sulphuric Acid, Sulphate of Soda, and Bleaching Powder. By JOHN LOMAS. 390 pages. With 232 Illustrations and Working Drawings. Second Edition. Royal 8vo, £1 10*s.* cloth.

"This book is written by a manufacturer for manufacturers. The working details of the most approved forms of apparatus are given, and these are accompanied by no less than 232 wood engravings, all of which may be used for the purposes of construction. Every step in the manufacture is very fully described in this manual, and each improvement explained."—*Athenæum.*

The Blowpipe.

THE BLOWPIPE IN CHEMISTRY, MINERALOGY, AND GEOLOGY. Containing all known Methods of Anhydrous Analysis, Working Examples, and Instructions for Making Apparatus. By Lieut.-Col. W. A. Ross, R.A. With 120 Illustrations. New Edition. Crown 8vo, 5*s.*

"The student who goes through the course of experimentation here laid down will gain a better insight into inorganic chemistry and mineralogy than if he had 'got up' any of the best text-books of the day, and passed any number of examinations in their contents."—*Chemical News.*

Commercial Chemical Analysis.

THE COMMERCIAL HANDBOOK OF CHEMICAL ANALYSIS; or, Practical Instructions for the determination of the Intrinsic or Commercial Value of Substances used in Manufactures, Trades, and the Arts. By A. NORMANDY. New Edition by H. M. NOAD, F.R.S. Cr. 8vo, 12*s.* 6*d.* cl.

"Essential to the analysts appointed under the new Act. The most recent results are given, and the work is well edited and carefully written."—*Nature.*

Brewing.

A HANDBOOK FOR YOUNG BREWERS. By HERBERT EDWARDS WRIGHT, B.A. An Entirely New Edition, much Enlarged. [*In the press.*

Analysis and Valuation of Fuels.

FUELS; SOLID, LIQUID AND GASEOUS, Their Analysis and Valuation. For the Use of Chemists and Engineers. By H. J. PHILLIPS, F.C.S., Analytical and Consulting Chemist to the Great Eastern Railway. Crown 8vo, 3s. 6*d*. cloth. [*Just published*

"Ought to have its place in the laboratory of every metallurgical establishment, and wherever fuel is used on a large scale."—*Chemical News.*

"Mr. Phillips' new book cannot fail to be of wide interest, especially at the present time."—*Railway News.*

Dye-Wares and Colours.

THE MANUAL OF COLOURS AND DYE-WARES: Their Properties, Applications, Valuation, Impurities, and Sophistications. For the use of Dyers, Printers, Drysalters, Brokers, &c. By J. W. SLATER. Second Edition, Revised and greatly Enlarged. Crown 8vo, 7*s*. 6*d*. cloth.

"A complete encyclopædia of the *materia tinctoria*. The information given respecting each article is full and precise, and the methods of determining the value of articles such as these, so liable to sophistication, are given with clearness, and are practical as well as valuable."—*Chemist and Druggist.*

"There is no other work which covers precisely the same ground. To students preparing for examinations in dyeing and printing it will prove exceedingly useful."—*Chemical News.*

Pigments.

THE ARTIST'S MANUAL OF PIGMENTS. Showing their Composition, Conditions of Permanency, Non-Permanency, and Adulterations; Effects in Combination with Each Other and with Vehicles; and the most Reliable Tests of Purity. Together with the Science and Arts Department's Examination Questions on Painting. By H. C. STANDAGE. Second Edition. Crown 8vo, 2*s*. 6*d*. cloth.

"This work is indeed *multum-in-parvo*, and we can, with good conscience, recommend it to all who come in contact with pigments, whether as makers, dealers or users."—*Chemical Review.*

Gauging. Tables and Rules for Revenue Officers, Brewers, etc.

A POCKET BOOK OF MENSURATION AND GAUGING. Containing Tables, Rules and Memoranda for Revenue Officers, Brewers, Spirit Merchants, &c. By J. B. MANT (Inland Revenue). Second Edition, Revised. Oblong 18mo, 4*s*. leather, with elastic band. [*Just published.*

"This handy and useful book is adapted to the requirements of the Inland Revenue Department, and will be a favourite book of reference. The range of subjects is comprehensive, and the arrangement simple and clear."—*Civilian.*

"Should be in the hands of every practical brewer."—*Brewers' Journal.*

AGRICULTURE, FARMING, GARDENING, etc.

Youatt and Burn's Complete Grazier.

THE COMPLETE GRAZIER, and FARMER'S and CATTLE-BREEDER'S ASSISTANT. A Compendium of Husbandry; especially in the departments connected with the Breeding, Rearing, Feeding, and General Management of Stock; the Management of the Dairy, &c. With Directions for the Culture and Management of Grass Land, of Grain and Root Crops, the Arrangement of Farm Offices, the use of Implements and Machines, and on Draining, Irrigation, Warping, &c.; and the Application and Relative Value of Manures. By WILLIAM YOUATT, Esq., V.S., and ROBERT SCOTT BURN. A New Edition, partly Re-Written and greatly Enlarged by W. FREAM, B.Sc. Lond., LL.D. One large 8vo Volume, nearly 1,000 pages. [*In preparation.*

Agricultural Facts and Figures.

NOTE-BOOK OF AGRICULTURAL FACTS AND FIGURES FOR FARMERS AND FARM STUDENTS. By PRIMROSE MCCONNELL, Fellow of the Highland and Agricultural Society; late Professor of Agriculture, Glasgow Veterinary College. Third Edition. Royal 32mo, full roan, gilt edges, with elastic band, 4*s*.

"The most complete and comprehensive Note-book for Farmers and Farm Students that we have seen. It literally teems with information, and we can cordially recommend it to all connected with agrculture."—*North British Agriculturist.*

Flour Manufacture, Milling, etc.

FLOUR MANUFACTURE: A Treatise on Milling Science and Practice. By FRIEDRICH KICK, Imperial Regierungsrath, Professor of Mechanical Technology in the Imperial German Polytechnic Institute, Prague. Translated from the Second Enlarged and Revised Edition with Supplement. By H. H. P. POWLES, A.M.I.C.E. Nearly 400 pp. Illustrated with 28 Folding Plates, and 167 Woodcuts. Royal 8vo, 25s. cloth.

'This valuable work is, and will remain, the standard authority on the science of milling. . . . The miller who has read and digested this work will have laid the foundation, so to speak, of a successful career; he will have acquired a number of general principles which he can proceed to apply. In this handsome volume we at last have the accepted text-book of modern milling in good, sound English, which has little, if any, trace of the German idiom."—*The Miller.*

"The appearance of this celebrated work in English is very opportune, and British millers will, we are sure, not be slow in availing themselves of its pages."—*Millers' Gazette.*

Small Farming.

SYSTEMATIC SMALL FARMING; or, The Lessons of my Farm. Being an Introduction to Modern Farm Practice for Small Farmers in the Culture of Crops; The Feeding of Cattle; The Management of the Dairy, Poultry and Pigs, &c. &c. By ROBERT SCOTT BURN, Author of "Outlines of Landed Estates' Management." Numerous Illusts., cr. 8vo, 6s. cloth.

"This is the completest book of its class we have seen, and one which every amateur farmer will read with pleasure and accept as a guide."—*Field.*

"The volume contains a vast amount of useful information. No branch of farming is left untouched, from the labour to be done to the results achieved. It may be safely recommended to all who think they will be in paradise when they buy or rent a three-acre farm."—*Glasgow Herald.*

Modern Farming.

OUTLINES OF MODERN FARMING. By R. SCOTT BURN. Soils, Manures, and Crops—Farming and Farming Economy—Cattle, Sheep, and Horses — Management of Dairy, Pigs and Poultry — Utilisation of Town-Sewage, Irrigation, &c. Sixth Edition. In One Vol., 1,250 pp., half-bound, profusely Illustrated, 12s.

"The aim of the author has been to make his work at once comprehensive and trustworthy, and in this aim he has succeeded to a degree which entitles him to much credit."—*Morning Advertiser.* "No farmer should be without this book."—*Banbury Guardian.*

Agricultural Engineering.

FARM ENGINEERING, THE COMPLETE TEXT-BOOK OF. Comprising Draining and Embanking; Irrigation and Water Supply; Farm Roads, Fences, and Gates; Farm Buildings, their Arrangement and Construction, with Plans and Estimates; Barn Implements and Machines; Field Implements and Machines; Agricultural Surveying, Levelling, &c. By Prof. JOHN SCOTT, Editor of the "Farmers' Gazette," late Professor of Agriculture and Rural Economy at the Royal Agricultural College, Cirencester, &c. &c. In One Vol., 1,150 pages, half-bound, with over 600 Illustrations, 12s.

"Written with great care, as well as with knowledge and ability. The author has done his work well; we have found him a very trustworthy guide wherever we have tested his statements. The volume will be of great value to agricultural students."—*Mark Lane Express.*

"For a young agriculturist we know of no handy volume likely to be more usefully studied." —*Bell's Weekly Messenger.*

English Agriculture.

THE FIELDS OF GREAT BRITAIN: A Text-Book of Agriculture, adapted to the Syllabus of the Science and Art Department. For Elementary and Advanced Students. By HUGH CLEMENTS (Board of Trade). Second Ed., Revised, with Additions. 18mo, 2s. 6d. cl. [*Just published.*

"A most comprehensive volume, giving a mass of information."—*Agricultural Economist.*

"It is a long time since we have seen a book which has pleased us more, or which contains such a vast and useful fund of knowledge."—*Educational Times.*

Tables for Farmers, etc.

TABLES, MEMORANDA, AND CALCULATED RESULTS for Farmers, Graziers, Agricultural Students, Surveyors, Land Agents Auctioneers, etc. With a New System of Farm Book-keeping. Selected and Arranged by SIDNEY FRANCIS. Second Edition, Revised. 272 pp., waistcoat-pocket size, 1s. 6d. limp leather. [*Just published.*

"Weighing less than 1 oz., and occupying no more space than a match box, it contains a mass of facts and calculations which has never before, in such handy form, been obtainable. Every operation on the farm is dealt with. The work may be taken as thoroughly accurate, the whole of the tables having been revised by Dr. Fream. We cordially recommend it."—*Bell's Weekly Messenger.*

"A marvellous little book. . . . The agriculturist who possesses himself of it will not be disappointed with his investment."—*The Farm.*

Farm and Estate Book-keeping.

BOOK-KEEPING FOR FARMERS & ESTATE OWNERS. A Practical Treatise, presenting, in Three Plans, a System adapted for all Classes of Farms. By JOHNSON M. WOODMAN, Chartered Accountant. Second Edition, Revised. Cr. 8vo, 3s. 6d. cl. bds.; or 2s. 6d. cl. limp. [*Just published.*

"The volume is a capital study of a most important subject."—*Agricultural Gazette.*

"Will be found of great assistance by those who intend to commence a system of book-keeping, the author's examples being clear and explicit, and his explanations, while full and accurate, being to a large extent free from technicalities."—*Live Stock Journal.*

Farm Account Book.

WOODMAN'S YEARLY FARM ACCOUNT BOOK. Giving a Weekly Labour Account and Diary, and showing the Income and Expenditure under each Department of Crops, Live Stock, Dairy, &c. &c. With Valuation, Profit and Loss Account, and Balance Sheet at the end of the Year, and an Appendix of Forms. Ruled and Headed for Entering a Complete Record of the Farming Operations. By JOHNSON M. WOODMAN, Chartered Accountant, Author of "Book-keeping for Farmers." Folio, 7s. 6d. half bound.

"Contains every requisite form for keeping farm accounts readily and accurately."—*Agriculture.*

Early Fruits, Flowers and Vegetables.

THE FORCING GARDEN; or, How to Grow Early Fruits, Flowers, and Vegetables. With Plans and Estimates for Building Glasshouses, Pits and Frames. Containing also Original Plans for Double Glazing, a New Method of Growing the Gooseberry under Glass, &c. &c., and on Ventilation, Protecting Vine Borders, &c. With Illustrations. By SAMUEL WOOD. Crown 8vo, 3s. 6d. cloth.

"A good book, and fairly fills a place that was in some degree vacant. The book is written with great care, and contains a great deal of valuable teaching."—*Gardeners' Magazine.*

"Mr. Wood's book is an original and exhaustive answer to the question 'How to Grow Early Fruits, Flowers and Vegetables?'"—*Land and Water.*

Good Gardening.

A PLAIN GUIDE TO GOOD GARDENING; or, How to Grow Vegetables, Fruits, and Flowers. With Practical Notes on Soils, Manures, Seeds, Planting, Laying-out of Gardens and Grounds, &c. By S. WOOD. Fourth Edition, with considerable Additions, &c., and numerous Illustrations. Crown 8vo, 3s. 6d. cloth.

"A very good book, and one to be highly recommended as a practical guide. The practical directions are excellent."—*Athenæum.*

"May be recommended to young gardeners, cottagers, and specially to amateurs, for the plain, simple, and trustworthy information it gives on common matters too often neglected."—*Gardeners' Chronicle.*

Gainful Gardening.

MULTUM-IN-PARVO GARDENING; or, How to make One Acre of Land produce £620 a-year by the Cultivation of Fruits and Vegetables; also, How to Grow Flowers in Three Glass Houses, so as to realise £176 per annum clear Profit. By SAMUEL WOOD, Author of "Good Gardening," &c. Fifth and cheaper Edition, Revised, with Additions. Crown 8vo, 1s. sewed.

"We are bound to recommend it as not only suited to the case of the amateur and gentleman's gardener, but to the market grower."—*Gardeners' Magazine.*

Gardening for Ladies.

THE LADIES' MULTUM-IN-PARVO FLOWER GARDEN, and Amateurs' Complete Guide. By S. WOOD. With Illusts. Cr. 8vo, 3s. 6d. cl.

"This volume contains a good deal of sound, common sense instruction."—*Florist.*

"Full of shrewd hints and useful instructions, based on a lifetime of experience."—*Scotsman.*

Receipts for Gardeners.

GARDEN RECEIPTS. Edited by CHARLES W. QUIN. 12mo, 1s. 6d. cloth limp.

"A useful and handy book, containing a good deal of valuable information."—*Athenæum.*

Market Gardening.

MARKET AND KITCHEN GARDENING. By Contributors to "The Garden." Compiled by C. W. SHAW, late Editor of "Gardening Illustrated." 12mo, 3s. 6d. cloth boards. [*Just published.*

"The most valuable compendium of kitchen and market-garden work published."—*Farmer.*

Cottage Gardening.

COTTAGE GARDENING; or, Flowers, Fruits, and Vegetables for Small Gardens. By E. HOBDAY. 12mo, 1s. 6d. cloth limp.

"Contains much useful information at a small charge."—*Glasgow Herald.*

LAND AND ESTATE MANAGEMENT, LAW, etc.

Hudson's Land Valuer's Pocket-Book.

THE LAND VALUER'S BEST ASSISTANT: Being Tables on a very much Improved Plan, for Calculating the Value of Estates. With Tables for reducing Scotch, Irish, and Provincial Customary Acres to Statute Measure, &c. By R. HUDSON, C.E. New Edition. Royal 32mo, leather, elastic band, 4*s.*

"This new edition includes tables for ascertaining the value of leases for any term of years; and for showing how to lay out plots of ground of certain acres in forms, square, round, &c., with valuable rules for ascertaining the probable worth of standing timber to any amount; and is of incalculable value to the country gentleman and professional man."—*Farmers' Journal.*

Ewart's Land Improver's Pocket-Book.

THE LAND IMPROVER'S POCKET-BOOK OF FORMULÆ, TABLES and MEMORANDA required in any Computation relating to the Permanent Improvement of Landed Property. By JOHN EWART, Land Surveyor and Agricultural Engineer. Second Edition, Revised. Royal 32mo, oblong, leather, gilt edges, with elastic band, 4*s.*

"A compendious and handy little volume."—*Spectator.*

Complete Agricultural Surveyor's Pocket-Book.

THE LAND VALUER'S AND LAND IMPROVER'S COMPLETE POCKET-BOOK. Consisting of the above Two Works bound together. Leather, gilt edges, with strap, 7*s.* 6*d.*

"Hudson's book is the best ready-reckoner on matters relating to the valuation of land and crops, and its combination with Mr. Ewart's work greatly enhances the value and usefulness of the latter-mentioned. . . . It is most useful as a manual for reference."—*North of England Farmer.*

Auctioneer's Assistant.

THE APPRAISER, AUCTIONEER, BROKER, HOUSE AND ESTATE AGENT AND VALUER'S POCKET ASSISTANT, for the Valuation for Purchase, Sale, or Renewal of Leases, Annuities and Reversions, and of property generally; with Prices for Inventories, &c. By JOHN WHEELER, Valuer, &c. Fifth Edition, re-written and greatly extended by C. NORRIS, Surveyor, Valuer, &c. Royal 32mo, 5*s.* cloth.

"A neat and concise book of reference, containing an admirable and clearly-arranged list of prices for inventories, and a very practical guide to determine the value of furniture, &c."—*Standard.*

"Contains a large quantity of varied and useful information as to the valuation for purchase, sale, or renewal of leases, annuities and reversions, and of property generally, with prices for inventories, and a guide to determine the value of interior fittings and other effects."—*Builder.*

Auctioneering.

AUCTIONEERS: Their Duties and Liabilities. A Manual of Instruction and Counsel for the Young Auctioneer. By ROBERT SQUIBBS, Auctioneer. Second Edition, Revised and partly Re-written. Demy 8vo, 12*s.* 6*d.* cloth. [*Just published.*

"The position and duties of auctioneers treated compendiously and clearly."—*Builder.*

"Every auctioneer ought to possess a copy of this excellent work."—*Ironmonger.*

"Of great value to the profession. . . . We readily welcome this book from the fact that it treats the subject in a manner somewhat new to the profession."—*Estates Gazette.*

Legal Guide for Pawnbrokers.

THE PAWNBROKERS', FACTORS' AND MERCHANTS' GUIDE TO THE LAW OF LOANS AND PLEDGES. With the Statutes and a Digest of Cases on Rights and Liabilities, Civil and Criminal, as to Loans and Pledges of Goods, Debentures, Mercantile and other Securities. By H. C. FOLKARD, Esq., Barrister-at-Law, Author of "The Law of Slander and Libel," &c. With Additions and Corrections. Fcap. 8vo, 3*s.* 6*d.* cloth.

"This work contains simply everything that requires to be known concerning the department of the law of which it treats. We can safely commend the book as unique and very nearly perfect." —*Iron.*

"The task undertaken by Mr. Folkard has been very satisfactorily performed. . . . Such explanations as are needful have been supplied with great clearness and with due regard to brevity." *City Press.*

Law of Patents.

PATENTS FOR INVENTIONS, AND HOW TO PROCURE THEM. Compiled for the Use of Inventors, Patentees and others. By G. G. M. HARDINGHAM, Assoc.Mem.Inst.C.E., &c. Demy 8vo, cloth, price 2s. 6d. [*Just published.*

Metropolitan Rating Appeals.

REPORTS OF APPEALS HEARD BEFORE THE COURT OF GENERAL ASSESSMENT SESSIONS, from the Year 1871 to 1885. By EDWARD RYDE and ARTHUR LYON RYDE. Fourth Edition, brought down to the Present Date, with an Introduction to the Valuation (Metropolis) Act, 1869, and an Appendix by WALTER C. RYDE, of the Inner Temple, Barrister-at-Law. 8vo, 16s. cloth.

"A useful work, occupying a place mid-way between a handbook for a lawyer and a guide to the surveyor. It is compiled by a gentleman eminent in his profession as a land agent, whose specialty, it is acknowledged, lies in the direction of assessing property for rating purposes."—*Land Agents' Record.*

"It is an indispensable work of reference for all engaged in assessment business."—*Journal of Gas Lighting.*

House Property.

HANDBOOK OF HOUSE PROPERTY. A Popular and Practical Guide to the Purchase, Mortgage, Tenancy, and Compulsory Sale of Houses and Land, including the Law of Dilapidations and Fixtures; with Examples of all kinds of Valuations, Useful Information on Building, and Suggestive Elucidations of Fine Art. By E. L. TARBUCK, Architect and Surveyor. Fourth Edition, Enlarged. 12mo, 5s. cloth.

"The advice is thoroughly practical."—*Law Journal.*

"For all who have dealings with house property, this is an indispensable guide."—*Decoration.*

"Carefully brought up to date, and much improved by the addition of a division on fine art.

"A well-written and thoughtful work."—*Land Agent's Record.*

Inwood's Estate Tables.

TABLES FOR THE PURCHASING OF ESTATES, Freehold, Copyhold, or Leasehold; Annuities, Advowsons, etc., and for the Renewing of Leases held under Cathedral Churches, Colleges, or other Corporate bodies, for Terms of Years certain, and for Lives; also for Valuing Reversionary Estates, Deferred Annuities, Next Presentations, &c.; together with SMART'S Five Tables of Compound Interest, and an Extension of the same to Lower and Intermediate Rates. By W. INWOOD. 23rd Edition, with considerable Additions, and new and valuable Tables of Logarithms for the more Difficult Computations of the Interest of Money, Discount, Annuities, &c., by M. FEDOR THOMAN, of the Société Crédit Mobilier of Paris. Crown 8vo, 8s. cloth.

"Those interested in the purchase and sale of estates, and in the adjustment of compensation cases, as well as in transactions in annuities, life insurances, &c., will find the present edition of eminent service."—*Engineering.*

"'Inwood's Tables' still maintain a most enviable reputation. The new issue has been enriched by large additional contributions by M. Fedor Thoman, whose carefully arranged Tables cannot fail to be of the utmost utility."—*Mining Journal.*

Agricultural and Tenant-Right Valuation.

THE AGRICULTURAL AND TENANT-RIGHT-VALUER'S ASSISTANT. A Practical Handbook on Measuring and Estimating the Contents, Weights and Values of Agricultural Produce and Timber, the Values of Estates and Agricultural Labour, Forms of Tenant-Right-Valuations, Scales of Compensation under the Agricultural Holdings Act, 1883, &c. &c. By TOM BRIGHT, Agricultural Surveyor. Crown 8vo, 3s. 6d. cloth.

"Full of tables and examples in connection with the valuation of tenant-right, estates, labour, contents, and weights of timber, and farm produce of all kinds."—*Agricultural Gazette.*

"An eminently practical handbook, full of practical tables and data of undoubted interest and value to surveyors and auctioneers in preparing valuations of all kinds."—*Farmer.*

Plantations and Underwoods.

POLE PLANTATIONS AND UNDERWOODS: A Practical Handbook on Estimating the Cost of Forming, Renovating, Improving and Grubbing Plantations and Underwoods, their Valuation for Purposes of Transfer, Rental, Sale or Assessment. By TOM BRIGHT, F.S.Sc., Author of "The Agricultural and Tenant-Right-Valuer's Assistant," &c. Crown 8vo, 3s. 6d. cloth. [*Just published.*

"Will be found very useful to those who are actually engaged in managing wood."—*Bell's Weekly Messenger.*

"To valuers, foresters and agents it will be a welcome aid."—*North British Agriculturist.*

"Well calculated to assist the valuer in the discharge of his duties, and of undoubted interest and use both to surveyors and auctioneers in preparing valuations of all kinds."—*Kent Herald.*

A Complete Epitome of the Laws of this Country.

EVERY MAN'S OWN LAWYER: A Handy-Book of the Principles of Law and Equity. By A Barrister. Twenty-eighth Edition. Revised and Enlarged. Including the Legislation of 1890, and including careful digests of *The Bankruptcy Act*, 1890; the *Directors' Liability Act*, 1890; the *Partnership Act*, 1890; the *Intestates' Estates Act*, 1890; the *Settled Land Act*, 1890; the *Housing of the Working Classes Act*, 1890; the *Infectious Disease (Prevention) Act*, 1890; the *Allotments Act*, 1890; the *Tenants' Compensation Act*, 1890; and the *Trustees' Appointment Act*, 1890; while other new Acts have been duly noted. Crown 8vo, 688 pp., price 6s. 8*d*. (saved at every consultation!), strongly bound in cloth. [*Just published.*

⁂ THE BOOK WILL BE FOUND TO COMPRISE (AMONGST OTHER MATTER)—

The Rights and Wrongs of Individuals—Landlord and Tenant—Vendors and Purchasers—Partners and Agents—Companies and Associations—Masters, Servants and Workmen—Leases and Mortgages—Church and Clergy, Ritual—Libel and Slander—Contracts and Agreements—Bonds and Bills of Sale—Cheques, Bills and Notes—Railway and Shipping Law—Bankruptcy and Insurance—Borrowers, Lenders and Sureties—Criminal Law—Parliamentary Elections—County Councils—Municipal Corporations—Parish Law, Churchwardens, etc.—Insanitary Dwellings and Areas—Public Health and Nuisances—Friendly and Building Societies—Copyright and Patents—Trade Marks and Designs—Husband and Wife, Divorce, etc.—Trustees and Executors—Guardian and Ward, Infants, etc.—Game Laws and Sporting—Horses, Horse-dealing and Dogs—Innkeepers, Licensing, etc.—Forms of Wills, Agreements, etc. etc.

Note.—*The object of this work is to enable those who consult it to help themselves to the law; and thereby to dispense, as far as possible, with professional assistance and advice. There are many wrongs and grievances which persons submit to from time to time through not knowing how or where to apply for redress; and many persons have as great a dread of a lawyer's office as of a lion's den. With this book at hand it is believed that many a* Six-and-Eightpence *may be saved; many a wrong redressed; many a right reclaimed; many a law suit avoided; and many an evil abated. The work has established itself as the standard legal adviser of all classes, and also made a reputation for itself as a useful book of reference for lawyers residing at a distance from law libraries, who are glad to have at hand a work embodying recent decisions and enactments.*

⁂ Opinions of the Press.

"It is a complete code of English Law, written in plain language, which all can understand. . . Should be in the hands of every business man, and all who wish to abolish lawyers' bills."—*Weekly Times.*

A useful and concise epitome of the law, compiled with considerable care."—*Law Magazine.*

"A complete digest of the most useful facts which constitute English law."—*Globe.*

"This excellent handbook. . . . Admirably done, admirably arranged, and admirably cheap."—*Leeds Mercury.*

'A concise, cheap and complete epitome of the English law. So plainly written that he who runs may read, and he who reads may understand."—*Figaro.*

"A dictionary of legal facts well put together. The book is a very useful one."—*Spectator.*

"A work which has long been wanted, which is thoroughly well done, and which we most cordially recommend."—*Sunday Times.*

"The latest edition of this popular book ought to be in every business establishment, and on every library table."—*Sheffield Post.*

Private Bill Legislation and Provisional Orders.

HANDBOOK FOR THE USE OF SOLICITORS AND ENGINEERS Engaged in Promoting Private Acts of Parliament and Provisional Orders, for the Authorization of Railways, Tramways, Works for the Supply of Gas and Water, and other undertakings of a like character. By L. Livingston Macassey, of the Middle Temple, Barrister-at-Law, and Member of the Institution of Civil Engineers; Author of "Hints on Water Supply." Demy 8vo, 950 pp., price 25*s*. cloth.

"The volume is a desideratum on a subject which can be only acquired by practical experience, and the order of procedure in Private Bill Legislation and Provisional Orders is followed. The author's suggestions and notes will be found of great value to engineers and others professionally engaged in this class of practice."—*Building News.*

"The author's double experience as an engineer and barrister has eminently qualified him for the task, and enabled him to approach the subject alike from an engineering and legal point of view. The volume will be found a great help both to engineers and lawyers engaged in promoting Private Acts of Parliament and Provisional Orders."—*Local Government Chronicle.*

OGDEN, SMALE AND CO. LIMITED, PRINTERS, GREAT SAFFRON HILL, E.C.

Weale's Rudimentary Series.

LONDON, 1862.
THE PRIZE MEDAL
Was awarded to the Publishers of
"WEALE'S SERIES."

A NEW LIST OF

WEALE'S SERIES

RUDIMENTARY SCIENTIFIC, EDUCATIONAL, AND CLASSICAL.

Comprising nearly Three Hundred and Fifty distinct works in almost every department of Science, Art, and Education, recommended to the notice of Engineers, Architects, Builders, Artisans, and Students generally, as well as to those interested in Workmen's Libraries, Literary and Scientific Institutions, Colleges, Schools, Science Classes, &c., &c.

☞ "WEALE'S SERIES includes Text-Books on almost every branch of Science and Industry, comprising such subjects as Agriculture, Architecture and Building, Civil Engineering, Fine Arts, Mechanics and Mechanical Engineering, Physical and Chemical Science, and many miscellaneous Treatises. The whole are constantly undergoing revision, and new editions, brought up to the latest discoveries in scientific research, are constantly issued. The prices at which they are sold are as low as their excellence is assured."—*American Literary Gazette.*

"Amongst the literature of technical education, WEALE'S SERIES has ever enjoyed a high reputation, and the additions being made by Messrs. CROSBY LOCKWOOD & SON render the series more complete, and bring the information upon the several subjects down to the present time."—*Mining Journal.*

"It is not too much to say that no books have ever proved more popular with, or more useful to, young engineers and others than the excellent treatises comprised in WEALE'S SERIES."—*Engineer.*

"The excellence of WEALE'S SERIES is now so well appreciated, that it would be wasting our space to enlarge upon their general usefulness and value."—*Builder.*

"The volumes of WEALE'S SERIES form one of the best collections of elementary technical books in any language."—*Architect.*

"WEALE'S SERIES has become a standard as well as an unrivalled collection of treatises in all branches of art and science."—*Public Opinion.*

PHILADELPHIA, 1876.
THE PRIZE MEDAL
Was awarded to the Publishers for
Books: Rudimentary, Scientific,
"WEALE'S SERIES," ETC.

CROSBY LOCKWOOD & SON,
7, STATIONERS' HALL COURT, LUDGATE HILL, LONDON, E.C.

WEALE'S RUDIMENTARY SCIENTIFIC SERIES.

Capio Lumen

*** The volumes of this Series are freely Illustrated with Woodcuts, or otherwise, where requisite. Throughout the following List it must be understood that the books are bound in limp cloth, unless otherwise stated; *but the volumes marked with a ‡ may also be had strongly bound in cloth boards for 6d. extra.*

N.B.—In ordering from this List it is recommended, as a means of facilitating business and obviating error, to quote the numbers affixed to the volumes, as well as the titles and prices.

CIVIL ENGINEERING, SURVEYING, ETC.

No.

31. *WELLS AND WELL-SINKING.* By John Geo. Swindell, A.R.I.B.A., and G. R. Burnell, C.E. Revised Edition. With a New Appendix on the Qualities of Water. Illustrated. 2s.

35. *THE BLASTING AND QUARRYING OF STONE,* for Building and other Purposes. By Gen. Sir J. Burgoyne, Bart. 1s. 6d.

43. *TUBULAR, AND OTHER IRON GIRDER BRIDGES,* particularly describing the Britannia and Conway Tubular Bridges. By G. Drysdale Dempsey, C.E. Fourth Edition. 2s.

44. *FOUNDATIONS AND CONCRETE WORKS,* with Practical Remarks on Footings, Sand, Concrete, Béton, Pile-driving, Caissons, and Cofferdams, &c. By E. Dobson. Fifth Edition. 1s. 6d.

60. *LAND AND ENGINEERING SURVEYING.* By T. Baker, C.E. Fourteenth Edition, revised by Professor J. R. Young. 2s.‡

80*. *EMBANKING LANDS FROM THE SEA.* With examples and Particulars of actual Embankments, &c. By J. Wiggins, F.G.S. 2s.

81. *WATER WORKS,* for the Supply of Cities and Towns. With a Description of the Principal Geological Formations of England as influencing Supplies of Water, &c. By S. Hughes, C.E. New Edition. 4s.‡

118. *CIVIL ENGINEERING IN NORTH AMERICA,* a Sketch of. By David Stevenson, F.R.S.E., &c. Plates and Diagrams. 3s.

167. *IRON BRIDGES, GIRDERS, ROOFS, AND OTHER* WORKS. By Francis Campin, C.E. 2s. 6d.‡

197. *ROADS AND STREETS.* By H. Law, C.E., revised and enlarged by D. K. Clark, C.E., including pavements of Stone, Wood, Asphalte, &c. 4s. 6d.‡

203. *SANITARY WORK IN THE SMALLER TOWNS AND IN* VILLAGES. By C. Slagg, A.M.I.C.E. Revised Edition. 3s.‡

212. *GAS-WORKS, THEIR CONSTRUCTION AND ARRANGEMENT*; and the Manufacture and Distribution of Coal Gas. Originally written by Samuel Hughes, C.E. Re-written and enlarged by William Richards, C.E. Seventh Edition, with important additions. 5s. 6d.‡

213. *PIONEER ENGINEERING.* A Treatise on the Engineering Operations connected with the Settlement of Waste Lands in New Countries. By Edward Dobson, Assoc. Inst. C.E. 4s. 6d.‡

216. *MATERIALS AND CONSTRUCTION;* A Theoretical and Practical Treatise on the Strains, Designing, and Erection of Works of Construction. By Francis Campin, C.E. Second Edition, revised. 3s.‡

219. *CIVIL ENGINEERING.* By Henry Law, M.Inst. C.E. Including Hydraulic Engineering by Geo. R. Burnell, M.Inst. C.E. Seventh Edition, revised, with large additions by D. Kinnear Clark, M.Inst. C.E. 6s. 6d., Cloth boards, 7s. 6d.

268. *THE DRAINAGE OF LANDS, TOWNS, & BUILDINGS.* By G. D. Dempsey, C.E. Revised, with large Additions on Recent Practice in Drainage Engineering, by D. Kinnear Clark, M.I.C.E. Second Edition, Corrected. 4s. 6d.‡ [*Just published.*

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

MECHANICAL ENGINEERING, ETC.

33. *CRANES*, the Construction of, and other Machinery for Raising Heavy Bodies. By JOSEPH GLYNN, F.R.S. Illustrated. 1s. 6d.

34. *THE STEAM ENGINE.* By Dr. LARDNER. Illustrated. 1s. 6d.

59. *STEAM BOILERS:* their Construction and Management. By R. ARMSTRONG, C.E. Illustrated. 1s. 6d.

82. *THE POWER OF WATER*, as applied to drive Flour Mills, and to give motion to Turbines, &c. By JOSEPH GLYNN, F.R.S. 2s.‡

98. *PRACTICAL MECHANISM*, the Elements of; and Machine Tools. By T. BAKER, C.E. With Additions by J. NASMYTH, C.E. 2s. 6d.‡

139. *THE STEAM ENGINE*, a Treatise on the Mathematical Theory of, with Rules and Examples for Practical Men. By T. BAKER, C.E. 1s. 6d.

164. *MODERN WORKSHOP PRACTICE*, as applied to Steam Engines, Bridges, Ship-building, Cranes, &c. By J. G. WINTON. Fourth Edition, much enlarged and carefully revised. 3s. 6d.‡ [*Just published.*

165. *IRON AND HEAT*, exhibiting the Principles concerned in the Construction of Iron Beams, Pillars, and Girders. By J. ARMOUR. 2s. 6d.‡

166. *POWER IN MOTION:* Horse-Power, Toothed-Wheel Gearing, Long and Short Driving Bands, and Angular Forces. By J. ARMOUR, 2s.‡

171. *THE WORKMAN'S MANUAL OF ENGINEERING* DRAWING. By J. MAXTON. 6th Edn. With 7 Plates and 350 Cuts. 3s. 6d.‡

190. *STEAM AND THE STEAM ENGINE*, Stationary and Portable. Being an Extension of the Elementary Treatise on the Steam Engine of MR. JOHN SEWELL. By D. K. CLARK, M.I.C.E. 3s. 6d.‡

200. *FUEL*, its Combustion and Economy. By C. W. WILLIAMS. With Recent Practice in the Combustion and Economy of Fuel—Coal, Coke Wood, Peat, Petroleum, &c.—by D. K. CLARK, M.I.C.E. 3s. 6d.‡

202. *LOCOMOTIVE ENGINES.* By G. D. DEMPSEY, C.E.; with large additions by D. KINNEAR CLARK, M.I.C.E. 3s.‡

211. *THE BOILERMAKER'S ASSISTANT* in Drawing, Templating, and Calculating Boiler and Tank Work. By JOHN COURTNEY. Practical Boiler Maker. Edited by D. K. CLARK, C.E. 100 Illustrations. 2s,

217. *SEWING MACHINERY:* Its Construction, History, &c., with full Technical Directions for Adjusting, &c. By J. W. URQUHART, C.E. 2s.‡

223. *MECHANICAL ENGINEERING.* Comprising Metallurgy, Moulding, Casting, Forging, Tools, Workshop Machinery, Manufacture of the Steam Engine, &c. By FRANCIS CAMPIN, C.E. Second Edition. 2s. 6d.‡

236. *DETAILS OF MACHINERY.* Comprising Instructions for the Execution of various Works in Iron. By FRANCIS CAMPIN, C.E. 3s.‡

237. *THE SMITHY AND FORGE;* including the Farrier's Art and Coach Smithing. By W. J. E. CRANE. Illustrated. 2s. 6d.‡

238. *THE SHEET-METAL WORKER'S GUIDE;* a Practical Handbook for Tinsmiths, Coppersmiths, Zincworkers, &c. With 94 Diagrams and Working Patterns. By W. J. E. CRANE. Second Edition, revised. 1s. 6d.

251. *STEAM AND MACHINERY MANAGEMENT:* with Hints on Construction and Selection. By M. POWIS BALE, M.I.M.E. 2s. 6d.‡

254. *THE BOILERMAKER'S READY-RECKONER.* By J. COURTNEY. Edited by D. K. CLARK, C.E. 4s., limp; 5s., half-bound.

255. *LOCOMOTIVE ENGINE-DRIVING.* A Practical Manual for Engineers in charge of Locomotive Engines. By MICHAEL REYNOLDS, M.S.E Eighth Edition. 3s. 6d., limp; 4s. 6d. cloth boards.

256. *STATIONARY ENGINE-DRIVING.* A Practical Manual Engineers in charge of Stationary Engines. By MICHAEL REYNOLDS, M.S.E. Third Edition. 3s. 6d. limp; 4s. 6d. cloth boards.

260. *IRON BRIDGES OF MODERATE SPAN:* their Construction and Erection. By HAMILTON W. PENDRED, C.E. 2s.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

MINING, METALLURGY, ETC.

4. *MINERALOGY*, Rudiments of; a concise View of the General Properties of Minerals. By A. RAMSAY, F.G.S., F.R.G.S., &c. Third Edition, revised and enlarged. Illustrated. 3s. 6d.‡

117. *SUBTERRANEOUS SURVEYING*, with and without the Magnetic Needle. By T. FENWICK and T. BAKER, C.E. Illustrated. 2s. 6d. ‡

135. *ELECTRO-METALLURGY;* Practically Treated. By ALEXANDER WATT. Ninth Edition, enlarged and revised, with additional Illustrations, and including the most recent Processes. 3s. 6d.‡

172. *MINING TOOLS*, Manual of. For the Use of Mine Managers, Agents, Students, &c. By WILLIAM MORGANS. 2s. 6d.

172*. *MINING TOOLS, ATLAS* of Engravings to Illustrate the above, containing 235 Illustrations, drawn to Scale. 4to. 4s. 6d.

176. *METALLURGY OF IRON.* Containing History of Iron Manufacture, Methods of Assay, and Analyses of Iron Ores, Processes of Manufacture of Iron and Steel, &c. By H. BAUERMAN, F.G.S. Sixth Edition, revised and enlarged. 5s.‡ [*Just published.*

180. *COAL AND COAL MINING.* By the late Sir WARINGTON W. SMYTH, M.A., F.R.S. Seventh Edition, revised. 3s. 6d.‡ [*Just published.*

195. *THE MINERAL SURVEYOR AND VALUER'S COMPLETE GUIDE.* By W. LINTERN, M.E. Third Edition, including Magnetic and Angular Surveying. With Four Plates. 3s. 6d.‡

214. *SLATE AND SLATE QUARRYING*, Scientific, Practical, and Commercial. By D. C. DAVIES, F.G.S., Mining Engineer, &c. 3s.‡

264. *A FIRST BOOK OF MINING AND QUARRYING*, with the Sciences connected therewith, for Primary Schools and Self-Instruction. By J. H. COLLINS, F.G.S. Second Edition, with additions. 1s. 6d.

ARCHITECTURE, BUILDING, ETC.

16. *ARCHITECTURE—ORDERS*—The Orders and their Æsthetic Principles. By W. H. LEEDS. Illustrated. 1s. 6d.

17. *ARCHITECTURE—STYLES*—The History and Description of the Styles of Architecture of Various Countries, from the Earliest to the Present Period. By T. TALBOT BURY, F.R.I.B.A., &c. Illustrated. 2s.
   ⁎ ORDERS AND STYLES OF ARCHITECTURE, *in One Vol.*, *3s. 6d.*

18. *ARCHITECTURE—DESIGN*—The Principles of Design in Architecture, as deducible from Nature and exemplified in the Works of the Greek and Gothic Architects. By E. L. GARBETT, Architect. Illustrated. 2s.6d.

⁎ *The three preceding Works, in One handsome Vol., half bound, entitled* "MODERN ARCHITECTURE," *price 6s.*

22. *THE ART OF BUILDING*, Rudiments of. General Principles of Construction, Materials used in Building, Strength and Use of Materials, Working Drawings, Specifications, and Estimates. By E. DOBSON, 2s.‡

25. *MASONRY AND STONECUTTING:* Rudimentary Treatise on the Principles of Masonic Projection and their application to Construction. By EDWARD DOBSON, M.R.I.B.A., &c. 2s. 6d.‡

42. *COTTAGE BUILDING.* By C. BRUCE ALLEN, Architect. Tenth Edition, revised and enlarged. With a Chapter on Economic Cottages for Allotments, by EDWARD E. ALLEN, C.E. 2s.

45. *LIMES, CEMENTS, MORTARS, CONCRETES, MASTICS,* PLASTERING, &c. By G. R. BURNELL, C.E. Thirteenth Edition. 1s. 6d.

57. *WARMING AND VENTILATION.* An Exposition of the General Principles as applied to Domestic and Public Buildings, Mines, Lighthouses, Ships, &c. By C. TOMLINSON, F.R.S., &c. Illustrated. 3s.

111. *ARCHES, PIERS, BUTTRESSES, &c.:* Experimental Essays on the Principles of Construction. By W. BLAND. Illustrated. 1s. 6d.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Architecture, Building, etc., *continued.*

116. *THE ACOUSTICS OF PUBLIC BUILDINGS;* or, The Principles of the Science of Sound applied to the purposes of the Architect and Builder. By T. ROGER SMITH, M.R.I.B.A., Architect. Illustrated. 1s. 6d.

127. *ARCHITECTURAL MODELLING IN PAPER,* the Art of. By T. A. RICHARDSON, Architect. Illustrated. 1s. 6d.

128. *VITRUVIUS—THE ARCHITECTURE OF MARCUS VITRUVIUS POLLO.* In Ten Books. Translated from the Latin by JOSEPH GWILT, F.S.A., F.R.A.S. With 23 Plates. 5s.

130. *GRECIAN ARCHITECTURE,* An Inquiry into the Principles of Beauty in; with an Historical View of the Rise and Progress of the Art in Greece. By the EARL OF ABERDEEN. 1s.

⁂ *The two preceding Works in One handsome Vol., half bound, entitled* "ANCIENT ARCHITECTURE," *price* 6s.

132. *THE ERECTION OF DWELLING-HOUSES.* Illustrated by a Perspective View, Plans, Elevations, and Sections of a pair of Semi-detached Villas, with the Specification, Quantities, and Estimates, &c. By S. H. BROOKS. New Edition, with Plates. 2s. 6d.‡

156. *QUANTITIES & MEASUREMENTS* in Bricklayers', Masons', Plasterers', Plumbers', Painters', Paperhangers', Gilders', Smiths', Carpenters' and Joiners' Work. By A. C. BEATON, Surveyor. New Edition. 1s. 6d.

175. *LOCKWOOD'S BUILDER'S PRICE BOOK FOR* 1891. A Comprehensive Handbook of the Latest Prices and Data for Builders, Architects, Engineers, and Contractors. Re-constructed, Re-written, and greatly Enlarged. By FRANCIS T. W. MILLER, A.R.I.B.A. 650 pages. 3s. 6d.; cloth boards, 4s. [*Just Published.*

182. *CARPENTRY AND JOINERY*—THE ELEMENTARY PRINCIPLES OF CARPENTRY. Chiefly composed from the Standard Work of THOMAS TREDGOLD, C.E. With a TREATISE ON JOINERY by E. WYNDHAM TARN, M.A. Fifth Edition, Revised. 3s. 6d.‡

182*. *CARPENTRY AND JOINERY. ATLAS* of 35 Plates to accompany the above. With Descriptive Letterpress. 4to. 6s.

185. *THE COMPLETE MEASURER;* the Measurement of Boards, Glass, &c.; Unequal-sided, Square-sided, Octagonal-sided, Round Timber and Stone, and Standing Timber, &c. By RICHARD HORTON. Fifth Edition. 4s.; strongly bound in leather, 5s.

187. *HINTS TO YOUNG ARCHITECTS.* By G. WIGHTWICK. New Edition. By G. H. GUILLAUME. Illustrated. 3s. 6d.‡

188. *HOUSE PAINTING, GRAINING, MARBLING, AND SIGN WRITING:* with a Course of Elementary Drawing for House-Painters, Sign-Writers, &c., and a Collection of Useful Receipts. By ELLIS A. DAVIDSON. Fifth Edition. With Coloured Plates. 5s. cloth limp; 6s. cloth boards.

189. *THE RUDIMENTS OF PRACTICAL BRICKLAYING.* In Six Sections: General Principles; Arch Drawing, Cutting, and Setting; Pointing; Paving, Tiling, Materials; Slating and Plastering; Practical Geometry, Mensuration, &c. By ADAM HAMMOND. Seventh Edition. 1s. 6d.

191. *PLUMBING.* A Text-Book to the Practice of the Art or Craft of the Plumber. With Chapters upon House Drainage and Ventilation. Fifth Edition. With 380 Illustrations. By W. P. BUCHAN. 3s. 6d.‡

192. *THE TIMBER IMPORTER'S, TIMBER MERCHANT'S,* and BUILDER'S STANDARD GUIDE. By R. E. GRANDY. 2s.

206. *A BOOK ON BUILDING, Civil and Ecclesiastical,* including CHURCH RESTORATION. With the Theory of Domes and the Great Pyramid, &c. By Sir EDMUND BECKETT, Bart., LL.D., Q.C., F.R.A.S. 4s. 6d.‡

226. *THE JOINTS MADE AND USED BY BUILDERS* in the Construction of various kinds of Engineering and Architectural Works. By WYVILL J. CHRISTY, Architect. With upwards of 160 Engravings on Wood. 3s.‡

228. *THE CONSTRUCTION OF ROOFS OF WOOD AND IRON.* By E. WYNDHAM TARN, M.A., Architect. Second Edition, revised. 1s. 6d.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Architecture, Building, etc., *continued.*

229. *ELEMENTARY DECORATION:* as applied to the Interior and Exterior Decoration of Dwelling-Houses, &c. By J. W. FACEY. 2s.

257. *PRACTICAL HOUSE DECORATION.* A Guide to the Art of Ornamental Painting. By JAMES W. FACEY. 2s. 6d.

⁂ *The two preceding Works, in One handsome Vol., half-bound, entitled* "HOUSE DECORATION, ELEMENTARY AND PRACTICAL," *price* 5s.

230. *HANDRAILING.* Showing New and Simple Methods for finding the Pitch of the Plank, Drawing the Moulds, Bevelling, Jointing-up, and Squaring the Wreath. By GEORGE COLLINGS. Second Edition, Revised including A TREATISE ON STAIRBUILDING. Plates and Diagrams. 2s. 6d.

247. *BUILDING ESTATES:* a Rudimentary Treatise on the Development, Sale, Purchase, and General Management of Building Land. By FOWLER MAITLAND, Surveyor. Second Edition, revised. 2s.

248. *PORTLAND CEMENT FOR USERS.* By HENRY FAIJA, Assoc. M. Inst. C.E. Third Edition, corrected. Illustrated. 2s.

252. *BRICKWORK:* a Practical Treatise, embodying the General and Higher Principles of Bricklaying, Cutting and Setting, &c. By F. WALKER. Second Edition, Revised and Enlarged. 1s. 6d.

23. *THE PRACTICAL BRICK AND TILE BOOK.* Comprising:
189. BRICK AND TILE MAKING, by E. DOBSON, A.I.C.E.; PRACTICAL BRICKLAY-
265. ING, by A. HAMMOND; BRICKCUTTING AND SETTING, by A. HAMMOND. 534 pp. with 270 Illustrations. 6s. Strongly half-bound.

253. *THE TIMBER MERCHANT'S, SAW-MILLER'S, AND* IMPORTER'S FREIGHT-BOOK AND ASSISTANT. By WM. RICHARDSON. With a Chapter on Speeds of Saw-Mill Machinery, &c. By M. POWIS BALE, A.M.Inst.C.E. 3s.‡

258. *CIRCULAR WORK IN CARPENTRY AND JOINERY.* A Practical Treatise on Circular Work of Single and Double Curvature. By GEORGE COLLINGS. Second Edition, 2s. 6d.

259. *GAS FITTING:* A Practical Handbook treating of every Description of Gas Laying and Fitting. By JOHN BLACK. With 122 Illustrations. 2s. 6d.‡

261. *SHORING AND ITS APPLICATION:* A Handbook for the Use of Students. By GEORGE H. BLAGROVE. 1s. 6d. [*Just published.*

265. *THE ART OF PRACTICAL BRICK CUTTING & SETTING.* By ADAM HAMMOND. With 90 Engravings. 1s. 6d. [*Just published.*

267. *THE SCIENCE OF BUILDING:* An Elementary Treatise on the Principles of Construction. Adapted to the Requirements of Architectural Students. By E. WYNDHAM TARN, M.A. Lond. Third Edition, Revised and Enlarged. With 59 Wood Engravings. 3s. 6d.‡ [*Just published.*

271. *VENTILATION:* a Text-book to the Practice of the Art of Ventilating Buildings, with a Supplementary Chapter upon Air Testing. By WILLIAM PATON BUCHAN, R.P., Sanitary and Ventilating Engineer, Author of "Plumbing," &c. 3s. 6d.‡ [*Just published.*

SHIPBUILDING, NAVIGATION, MARINE ENGINEERING, ETC.

51. *NAVAL ARCHITECTURE.* An Exposition of the Elementary Principles of the Science, and their Practical Application to Naval Construction. By J. PEAKE. Fifth Edition, with Plates and Diagrams. 3s. 6d.‡

53*. *SHIPS FOR OCEAN & RIVER SERVICE,* Elementary and Practical Principles of the Construction of. By H. A. SOMMERFELDT. 1s. 6d.

53**. *AN ATLAS OF ENGRAVINGS* to Illustrate the above. Twelve large folding plates. Royal 4to, cloth. 7s. 6d.

54. *MASTING, MAST-MAKING, AND RIGGING OF SHIPS,* Also Tables of Spars, Rigging, Blocks; Chain, Wire, and Hemp Ropes, &c., relative to every class of vessels. By ROBERT KIPPING, N.A. 2s.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Shipbuilding, Navigation, Marine Engineering, etc., *cont.*

54*. *IRON SHIP-BUILDING.* With Practical Examples and Details. By Johh Grantham, C.E. Fifth Edition. 4s.

55. *THE SAILOR'S SEA BOOK:* a Rudimentary Treatise on Navigation. By James Greenwood, B.A. With numerous Woodcuts and Coloured Plates. New and enlarged edition. By W. H. Rosser. 2s. 6d.‡

80. *MARINE ENGINES AND STEAM VESSELS.* By Robert Murray, C.E. Eighth Edition, thoroughly Revised, with Additions by the Author and by George Carlisle, C.E. 4s. 6d. limp; 5s. cloth boards.

83*bis*. *THE FORMS OF SHIPS AND BOATS.* By W. Bland. Seventh Edition, Revised, with numerous Illustrations and Models. 1s. 6d.

99. *NAVIGATION AND NAUTICAL ASTRONOMY,* in Theory and Practice. By Prof. J. R. Young. New Edition. 2s. 6d.

106. *SHIPS' ANCHORS,* a Treatise on. By G. Cotsell, N.A. 1s. 6d.

149. *SAILS AND SAIL-MAKING.* With Draughting, and the Centre of Effort of the Sails; Weights and Sizes of Ropes; Masting, Rigging, and Sails of Steam Vessels, &c. 12th Edition. By R. Kipping, N.A., 2s. 6d.‡

155. *ENGINEER'S GUIDE TO THE ROYAL & MERCANTILE* NAVIES. By a Practical Engineer. Revised by D. F. M'Carthy. 3s.

55 & 204. *PRACTICAL NAVIGATION.* Consisting of The Sailor's Sea-Book. By James Greenwood and W. H. Rosser. Together with the requisite Mathematical and Nautical Tables for the Working of the Problems. By H. Law, C.E., and Prof. J. R. Young. 7s. Half-bound.

AGRICULTURE, GARDENING, ETC.

61*. *A COMPLETE READY RECKONER FOR THE ADMEASUREMENT OF LAND, &c.* By A. Arman. Third Edition, revised and extended by C. Norris, Surveyor, Valuer, &c. 2s.

131. *MILLER'S, CORN MERCHANT'S, AND FARMER'S* READY RECKONER. Second Edition, with a Price List of Modern Flour-Mill Machinery, by W. S. Hutton, C.E. 2s.

140. *SOILS, MANURES, AND CROPS.* (Vol. 1. Outlines of Modern Farming.) By R. Scott Burn. Woodcuts. 2s.

141. *FARMING & FARMING ECONOMY,* Notes, Historical and Practical, on. (Vol. 2. Outlines of Modern Farming.) By R. Scott Burn. 3s.

142. *STOCK; CATTLE, SHEEP, AND HORSES.* (Vol. 3. Outlines of Modern Farming.) By R. Scott Burn. Woodcuts. 2s. 6d.

145. *DAIRY, PIGS, AND POULTRY,* Management of the. By R. Scott Burn. (Vol. 4. Outlines of Modern Farming.) 2s.

146. *UTILIZATION OF SEWAGE, IRRIGATION, AND* RECLAMATION OF WASTE LAND. (Vol. 5. Outlines of Modern Farming.) By R. Scott Burn. Woodcuts. 2s. 6d.

⁂ *Nos. 140-1-2-5-6, in One Vol., handsomely half-bound, entitled* "Outlines of Modern Farming." By Robert Scott Burn. *Price 12s.*

177. *FRUIT TREES,* The Scientific and Profitable Culture of. From the French of Du Breuil. Revised by Geo. Glenny. 187 Woodcuts. 3s. 6d.‡

198. *SHEEP; THE HISTORY, STRUCTURE, ECONOMY, AND* DISEASES OF. By W. C. Spooner, M.R.V.C., &c. Fifth Edition, enlarged, including Specimens of New and Improved Breeds. 3s. 6d.‡

201. *KITCHEN GARDENING MADE EASY.* By George M. F. Glenny. Illustrated. 1s. 6d.‡

207. *OUTLINES OF FARM MANAGEMENT, and the Organization of Farm Labour.* By R. Scott Burn. 2s. 6d.‡

208. *OUTLINES OF LANDED ESTATES MANAGEMENT* By R. Scott Burn. 2s. 6d.‡

⁂ *Nos. 207 & 208 in One Vol., handsomely half-bound, entitled* "Outlines of Landed Estates and Farm Management." By R. Scott Burn. *Price 6s.*

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Agriculture, Gardening, etc., *continued.*

209. *THE TREE PLANTER AND PLANT PROPAGATOR.* A Practical Manual on the Propagation of Forest Trees, Fruit Trees, Flowering Shrubs, Flowering Plants, &c. By SAMUEL WOOD. 2s.

210. *THE TREE PRUNER.* A Practical Manual on the Pruning of Fruit Trees, including also their Training and Renovation; also the Pruning of Shrubs, Climbers, and Flowering Plants. By SAMUEL WOOD. 1s. 6d.

⁂ *Nos.* 209 *&* 210 *in One Vol., handsomely half-bound, entitled* "THE TREE PLANTER, PROPAGATOR, AND PRUNER." By SAMUEL WOOD. *Price* 3*s.* 6d.

218. *THE HAY AND STRAW MEASURER:* Being New Tables for the Use of Auctioneers, Valuers, Farmers, Hay and Straw Dealers, &c. By JOHN STEELE. Fourth Edition. 2s.

222. *SUBURBAN FARMING.* The Laying-out and Cultivation of Farms, adapted to the Produce of Milk, Butter, and Cheese, Eggs, Poultry, and Pigs. By Prof. JOHN DONALDSON and R. SCOTT BURN. 3s. 6d.‡

231. *THE ART OF GRAFTING AND BUDDING.* By CHARLES BALTET. With Illustrations. 2s. 6d.‡

232. *COTTAGE GARDENING;* or, Flowers, Fruits, and Vegetables for Small Gardens. By E. HOBDAY. 1s. 6d.

233. *GARDEN RECEIPTS.* Edited by CHARLES W. QUIN. 1s. 6d.

234. *MARKET AND KITCHEN GARDENING.* By C. W. SHAW, late Editor of "Gardening Illustrated." 3s.‡ [*Just published.*

239. *DRAINING AND EMBANKING.* A Practical Treatise, embodying the most recent experience in the Application of Improved Methods. By JOHN SCOTT, late Professor of Agriculture and Rural Economy at the Royal Agricultural College, Cirencester. With 68 Illustrations. 1s. 6d.

240. *IRRIGATION AND WATER SUPPLY.* A Treatise on Water Meadows, Sewage Irrigation, and Warping; the Construction of Wells, Ponds, and Reservoirs, &c. By Prof. JOHN SCOTT. With 34 Illus. 1s. 6d.

241. *FARM ROADS, FENCES, AND GATES.* A Practical Treatise on the Roads, Tramways, and Waterways of the Farm; the Principles of Enclosures; and the different kinds of Fences, Gates, and Stiles. By Professor JOHN SCOTT. With 75 Illustrations. 1s. 6d.

242. *FARM BUILDINGS.* A Practical Treatise on the Buildings necessary for various kinds of Farms, their Arrangement and Construction, with Plans and Estimates. By Prof. JOHN SCOTT. With 105 Illus. 2s.

243. *BARN IMPLEMENTS AND MACHINES.* A Practical Treatise on the Application of Power to the Operations of Agriculture; and on various Machines used in the Threshing-barn, in the Stock-yard, and in the Dairy, &c. By Prof. J. SCOTT. With 123 Illustrations. 2s.

244. *FIELD IMPLEMENTS AND MACHINES.* A Practical Treatise on the Varieties now in use, with Principles and Details of Construction, their Points of Excellence, and Management. By Professor JOHN SCOTT. With 138 Illustrations. 2s.

245. *AGRICULTURAL SURVEYING.* A Practical Treatise on Land Surveying, Levelling, and Setting-out; and on Measuring and Estimating Quantities, Weights, and Values of Materials, Produce, Stock, &c. By Prof. JOHN SCOTT. With 62 Illustrations. 1s. 6d.

⁂ *Nos.* 239 *to* 245 *in One Vol., handsomely half-bound, entitled* "THE COMPLETE TEXT-BOOK OF FARM ENGINEERING." By Professor JOHN SCOTT. *Price* 12*s.*

250. *MEAT PRODUCTION.* A Manual for Producers, Distributors, &c. By JOHN EWART. 2s. 6d.‡

266. *BOOK-KEEPING FOR FARMERS & ESTATE OWNERS.* By J. M. WOODMAN, Chartered Accountant. 2s. 6d. cloth limp; 3s. 6d. cloth boards. [*Just published.*

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

MATHEMATICS, ARITHMETIC, ETC.

32. *MATHEMATICAL INSTRUMENTS*, a Treatise on; Their Construction, Adjustment, Testing, and Use concisely Explained. By J. F. Heather, M.A. Fourteenth Edition, revised, with additions, by A. T. Walmisley, M.I.C.E., Fellow of the Surveyors' Institution. Original Edition, in 1 vol., Illustrated. 2s.‡ [*Just published.*

⁂ *In ordering the above, be careful to say, "Original Edition" (No. 32), to distinguish it from the Enlarged Edition in 3 vols. (Nos. 168-9-70.)*

76. *DESCRIPTIVE GEOMETRY*, an Elementary Treatise on; with a Theory of Shadows and of Perspective, extracted from the French of G. Monge. To which is added, a description of the Principles and Practice of Isometrical Projection. By J. F. Heather, M.A. With 14 Plates. 2s.

178. *PRACTICAL PLANE GEOMETRY:* giving the Simplest Modes of Constructing Figures contained in one Plane and Geometrical Construction of the Ground. By J. F. Heather, M.A. With 215 Woodcuts. 2s.

83. *COMMERCIAL BOOK-KEEPING.* With Commercial Phrases and Forms in English, French, Italian, and German. By James Haddon, M.A., Arithmetical Master of King's College School, London. 1s. 6d.

84. *ARITHMETIC*, a Rudimentary Treatise on: with full Explanations of its Theoretical Principles, and numerous Examples for Practice. By Professor J. R. Young. Eleventh Edition. 1s. 6d.

84*. A Key to the above, containing Solutions in full to the Exercises, together with Comments, Explanations, and Improved Processes, for the Use of Teachers and Unassisted Learners. By J. R. Young. 1s. 6d.

85. *EQUATIONAL ARITHMETIC*, applied to Questions of Interest, Annuities, Life Assurance, and General Commerce; with various Tables by which all Calculations may be greatly facilitated. By W. Hipsley. 2s.

86. *ALGEBRA*, the Elements of. By James Haddon, M.A. With Appendix, containing miscellaneous Investigations, and a Collection of Problems in various parts of Algebra. 2s.,

86*. A Key and Companion to the above Book, forming an extensive repository of Solved Examples and Problems in Illustration of the various Expedients necessary in Algebraical Operations. By J. R. Young. 1s. 6d.

88.
89. *EUCLID*, The Elements of: with many additional Propositions and Explanatory Notes: to which is prefixed, an Introductory Essay on Logic. By Henry Law, C.E. 2s. 6d.‡

⁂ *Sold also separately, viz.:—*

88. Euclid, The First Three Books. By Henry Law, C.E. 1s. 6d.
89. Euclid, Books 4, 5, 6, 11, 12. By Henry Law, C.E. 1s. 6d.

90. *ANALYTICAL GEOMETRY AND CONIC SECTIONS*, By James Hann. A New Edition, by Professor J. R. Young. 2s.‡

91. *PLANE TRIGONOMETRY*, the Elements of. By James Hann, formerly Mathematical Master of King's College, London. 1s. 6d.

92. *SPHERICAL TRIGONOMETRY*, the Elements of. By James Hann. Revised by Charles H. Dowling, C.E. 1s.

⁂ *Or with "The Elements of Plane Trigonometry," in One Volume, 2s. 6d.*

93. *MENSURATION AND MEASURING.* With the Mensuration and Levelling of Land for the Purposes of Modern Engineering. By T. Baker, C.E. New Edition by E. Nugent, C.E. Illustrated. 1s. 6d.

101. *DIFFERENTIAL CALCULUS*, Elements of the. By W. S. B. Woolhouse, F.R.A.S., &c. 1s. 6d.

102. *INTEGRAL CALCULUS*, Rudimentary Treatise on the. By Homersham Cox, B.A. Illustrated. 1s.

136. *ARITHMETIC*, Rudimentary, for the Use of Schools and Self-Instruction. By James Haddon, M.A. Revised by A. Arman. 1s. 6d.

137. A Key to Haddon's Rudimentary Arithmetic. By A. Arman. 1s. 6d.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Mathematics, Arithmetic, etc., *continued.*

168. *DRAWING AND MEASURING INSTRUMENTS.* Including—I. Instruments employed in Geometrical and Mechanical Drawing, and in the Construction, Copying, and Measurement of Maps and Plans. II. Instruments used for the purposes of Accurate Measurement, and for Arithmetical Computations. By J. F. HEATHER, M.A. Illustrated. 1s. 6d

169. *OPTICAL INSTRUMENTS.* Including (more especially) Telescopes, Microscopes, and Apparatus for producing copies of Maps and Plans by Photography. By J. F. HEATHER, M.A. Illustrated. 1s. 6d.

170. *SURVEYING AND ASTRONOMICAL INSTRUMENTS.* Including—I. Instruments Used for Determining the Geometrical Features of a portion of Ground. II. Instruments Employed in Astronomical Observations. By J. F. HEATHER, M.A. Illustrated. 1s. 6d.

⁂ *The above three volumes form an enlargement of the Author's original work "Mathematical Instruments."* (*See No.* 32 *in the Series.*)

168. 169. 170. } *MATHEMATICAL INSTRUMENTS.* By J. F. HEATHER, M.A. Enlarged Edition, for the most part entirely re-written. The 3 Parts as above, in One thick Volume. With numerous Illustrations. 4s. 6d.‡

158. *THE SLIDE RULE, AND HOW TO USE IT;* containing full, easy, and simple Instructions to perform all Business Calculations with unexampled rapidity and accuracy. By CHARLES HOARE, C.E. Fifth Edition. With a Slide Rule in tuck of cover. 2s. 6d.‡

196. *THEORY OF COMPOUND INTEREST AND ANNUITIES;* with Tables of Logarithms for the more Difficult Computations of Interest, Discount, Annuities, &c. By FÉDOR THOMAN. 4s.‡

199. *THE COMPENDIOUS CALCULATOR;* or, Easy and Concise Methods of Performing the various Arithmetical Operations required in Commercial and Business Transactions; together with Useful Tables. By D. O'GORMAN. Twenty-seventh Edition, carefully revised by C. NORRIS. 2s. 6d., cloth limp; 3s. 6d., strongly half-bound in leather.

204. *MATHEMATICAL TABLES,* for Trigonometrical, Astronomical, and Nautical Calculations; to which is prefixed a Treatise on Logarithms. By HENRY LAW, C.E. Together with a Series of Tables for Navigation and Nautical Astronomy. By Prof. J. R. YOUNG. New Edition. 4s.

204*. *LOGARITHMS.* With Mathematical Tables for Trigonometrical, Astronomical, and Nautical Calculations. By HENRY LAW, M.Inst.C.E. New and Revised Edition. (Forming part of the above Work). 3s.

221. *MEASURES, WEIGHTS, AND MONEYS OF ALL NATIONS,* and an Analysis of the Christian, Hebrew, and Mahometan Calendars. By W. S. B. WOOLHOUSE, F.R.A.S., F.S.S. Sixth Edition. 2s.‡

227. *MATHEMATICS AS APPLIED TO THE CONSTRUCTIVE ARTS.* Illustrating the various processes of Mathematical Investigation, by means of Arithmetical and Simple Algebraical Equations and Practical Examples. By FRANCIS CAMPIN, C.E. Second Edition. 3s.‡

PHYSICAL SCIENCE, NATURAL PHILOSOPHY, ETC.

1. *CHEMISTRY.* By Professor GEORGE FOWNES, F.R.S. With an Appendix on the Application of Chemistry to Agriculture. 1s.

2. *NATURAL PHILOSOPHY,* Introduction to the Study of. By C. TOMLINSON. Woodcuts. 1s. 6d.

6. *MECHANICS,* Rudimentary Treatise on. By CHARLES TOMLINSON. Illustrated. 1s. 6d.

7. *ELECTRICITY;* showing the General Principles of Electrical Science, and the purposes to which it has been applied. By Sir W. SNOW HARRIS, F.R.S., &c. With Additions by R. SABINE, C.E., F.S.A. 1s. 6d.

7*. *GALVANISM.* By Sir W. SNOW HARRIS. New Edition by ROBERT SABINE, C.E., F.S.A. 1s. 6d.

8. *MAGNETISM;* being a concise Exposition of the General Principles of Magnetical Science. By Sir W. SNOW HARRIS. New Edition, revised by H. M. NOAD, Ph.D. With 165 Woodcuts. 3s. 6d.‡

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

Physical Science, Natural Philosophy, etc., *continued.*

11. *THE ELECTRIC TELEGRAPH;* its History and Progress; with Descriptions of some of the Apparatus. By R. SABINE, C.E., F.S.A. 3s.

12. *PNEUMATICS,* including Acoustics and the Phenomena of Wind Currents, for the Use of Beginners. By CHARLES TOMLINSON, F.R.S. Fourth Edition, enlarged. Illustrated. 1s. 6d. [*Just published.*

72. *MANUAL OF THE MOLLUSCA;* a Treatise on Recent and Fossil Shells. By Dr. S. P. WOODWARD, A.L.S. Fourth Edition. With Plates and 300 Woodcuts. 7s. 6d., cloth.

96. *ASTRONOMY.* By the late Rev. ROBERT MAIN, M.A. Third Edition, by WILLIAM THYNNE LYNN, B.A., F.R.A.S. 2s.

97. *STATICS AND DYNAMICS,* the Principles and Practice of; embracing also a clear development of Hydrostatics, Hydrodynamics, and Central Forces. By T. BAKER, C.E. Fourth Edition. 1s. 6d.

173. *PHYSICAL GEOLOGY,* partly based on Major-General PORTLOCK'S "Rudiments of Geology." By RALPH TATE, A.L.S., &c. Woodcuts. 2s.

174. *HISTORICAL GEOLOGY,* partly based on Major-General PORTLOCK'S "Rudiments." By RALPH TATE, A.L.S., &c. Woodcuts. 2s. 6d.

173 & 174. *RUDIMENTARY TREATISE ON GEOLOGY,* Physical and Historical. Partly based on Major-General PORTLOCK'S "Rudiments of Geology." By RALPH TATE, A.L.S., F.G.S., &c. In One Volume. 4s. 6d.‡

183 & 184. *ANIMAL PHYSICS,* Handbook of. By Dr. LARDNER, D.C.L., formerly Professor of Natural Philosophy and Astronomy in University College, Lond. With 520 Illustrations. In One Vol. 7s. 6d., cloth boards.

⁂ *Sold also in Two Parts, as follows:—*

183. ANIMAL PHYSICS. By Dr. LARDNER. Part I., Chapters I.—VII. 4s.
184. ANIMAL PHYSICS. By Dr. LARDNER. Part II., Chapters VIII.—XVIII. 3s.

269. *LIGHT:* an Introduction to the Science of Optics, for the Use of Students of Architecture, Engineering, and other Applied Sciences. By E. WYNDHAM TARN, M.A. 1s. 6d. [*Just published.*

FINE ARTS.

20. *PERSPECTIVE FOR BEGINNERS.* Adapted to Young Students and Amateurs in Architecture, Painting, &c. By GEORGE PYNE. 2s.

40 *GLASS STAINING, AND THE ART OF PAINTING ON GLASS.* From the German of Dr. GESSERT and EMANUEL OTTO FROMBERG. With an Appendix on THE ART OF ENAMELLING. 2s. 6d.

69. *MUSIC,* A Rudimentary and Practical Treatise on. With numerous Examples. By CHARLES CHILD SPENCER. 2s. 6d.

71. *PIANOFORTE,* The Art of Playing the. With numerous Exercises & Lessons from the Best Masters. By CHARLES CHILD SPENCER. 1s. 6d.

69-71. *MUSIC & THE PIANOFORTE.* In one vol. Half bound, 5s.

181. *PAINTING POPULARLY EXPLAINED,* including Fresco, Oil, Mosaic, Water Colour, Water-Glass, Tempera, Encaustic, Miniature, Painting on Ivory, Vellum, Pottery, Enamel, Glass, &c. With Historical Sketches of the Progress of the Art by THOMAS JOHN GULLICK, assisted by JOHN TIMBS, F.S.A. Fifth Edition, revised and enlarged. 5s.‡

186. *A GRAMMAR OF COLOURING,* applied to Decorative Painting and the Arts. By GEORGE FIELD. New Edition, enlarged and adapted to the Use of the Ornamental Painter and Designer. By ELLIS A. DAVIDSON. With two new Coloured Diagrams, &c. 3s.‡

246. *A DICTIONARY OF PAINTERS, AND HANDBOOK FOR PICTURE AMATEURS;* including Methods of Painting, Cleaning, Relining and Restoring, Schools of Painting, &c. With Notes on the Copyists and Imitators of each Master. By PHILIPPE DARYL. 2s. 6d.‡

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

INDUSTRIAL AND USEFUL ARTS.

23. *BRICKS AND TILES*, Rudimentary Treatise on the Manufacture of. By E. DOBSON, M.R.I.B.A. Illustrated, 3s.‡

67. *CLOCKS, WATCHES, AND BELLS*, a Rudimentary Treatise on. By Sir EDMUND BECKETT, LL.D., Q.C. Seventh Edition, revised and enlarged. 4s. 6d. limp; 5s. 6d. cloth boards.

83**. *CONSTRUCTION OF DOOR LOCKS*. Compiled from the Papers of A. C. HOBBS, and Edited by CHARLES TOMLINSON, F.R.S. 2s. 6d.

162. *THE BRASS FOUNDER'S MANUAL;* Instructions for Modelling, Pattern-Making, Moulding, Turning, Filing, Burnishing, Bronzing, &c. With copious Receipts, &c. By WALTER GRAHAM. 2s.‡

205. *THE ART OF LETTER PAINTING MADE EASY*. By J. G. BADENOCH. Illustrated with 12 full-page Engravings of Examples. 1s. 6d.

215. *THE GOLDSMITH'S HANDBOOK*, containing full Instructions for the Alloying and Working of Gold. By GEORGE E. GEE, 3s.‡

225. *THE SILVERSMITH'S HANDBOOK*, containing full Instructions for the Alloying and Working of Silver. By GEORGE E. GEE. 3s.‡

⁂ *The two preceding Works, in One handsome Vol., half-bound, entitled* "THE GOLDSMITH'S & SILVERSMITH'S COMPLETE HANDBOOK," 7s.

249. *THE HALL-MARKING OF JEWELLERY PRACTICALLY CONSIDERED*. By GEORGE E. GEE. 3s.‡

224. *COACH BUILDING*, A Practical Treatise, Historical and Descriptive. By J. W. BURGESS. 2s. 6d.‡

235. *PRACTICAL ORGAN BUILDING*. By W. E. DICKSON, M.A., Precentor of Ely Cathedral. Illustrated. 2s. 6d.‡

262. *THE ART OF BOOT AND SHOEMAKING*. By JOHN BEDFORD LENO. Numerous Illustrations. Third Edition. 2s.

263. *MECHANICAL DENTISTRY:* A Practical Treatise on the Construction of the Various Kinds of Artificial Dentures, with Formulæ, Tables, Receipts, &c. By CHARLES HUNTER. Third Edition. 3s.‡

270. *WOOD ENGRAVING:* A Practical and Easy Introduction to the Study of the Art. By W. N. BROWN. 1s. 6d.

MISCELLANEOUS VOLUMES.

36. *A DICTIONARY OF TERMS used in ARCHITECTURE, BUILDING, ENGINEERING, MINING, METALLURGY, ARCHÆOLOGY, the FINE ARTS, &c.* By JOHN WEALE. Fifth Edition. Revised by ROBERT HUNT, F.R.S. Illustrated. 5s. limp; 6s. cloth boards.

50. *THE LAW OF CONTRACTS FOR WORKS AND SERVICES*. By DAVID GIBBONS. Third Edition, enlarged. 3s.‡

112. *MANUAL OF DOMESTIC MEDICINE*. By R. GOODING, B.A., M.D. A Family Guide in all Cases of Accident and Emergency. 2s.‡

112*. *MANAGEMENT OF HEALTH*. A Manual of Home and Personal Hygiene. By the Rev. JAMES BAIRD, B.A. 1s.

150. *LOGIC*, Pure and Applied. By S. H. EMMENS. 1s. 6d.

153. *SELECTIONS FROM LOCKE'S ESSAYS ON THE HUMAN UNDERSTANDING*. With Notes by S. H. EMMENS. 2s.

154. *GENERAL HINTS TO EMIGRANTS*. 2s.

157. *THE EMIGRANT'S GUIDE TO NATAL*. By ROBERT JAMES MANN, F.R.A.S., F.M.S. Second Edition. Map. 2s.

193. *HANDBOOK OF FIELD FORTIFICATION*. By Major W. W. KNOLLYS, F.R.G.S. With 163 Woodcuts. 3s.‡

194. *THE HOUSE MANAGER:* Being a Guide to Housekeeping. Practical Cookery, Pickling and Preserving, Household Work, Dairy Managoment, &c. By AN OLD HOUSEKEEPER. 3s. 6d.‡

194, *HOUSE BOOK (The)*. Comprising:—I. THE HOUSE MANAGER.
112 & By an OLD HOUSEKEEPER. II. DOMESTIC MEDICINE. By R. GOODING, M.D.
112*. III. MANAGEMENT OF HEALTH. By J. BAIRD. In One Vol., half-bound, 6s.

☞ *The ‡ indicates that these vols. may be had strongly bound at 6d. extra.*

EDUCATIONAL AND CLASSICAL SERIES.

HISTORY.

1. **England, Outlines of the History of;** more especially with reference to the Origin and Progress of the English Constitution. By WILLIAM DOUGLAS HAMILTON, F.S.A., of Her Majesty's Public Record Office. 4th Edition, revised. 5s.; cloth boards, 6s.

5. **Greece, Outlines of the History of;** in connection with the Rise of the Arts and Civilization in Europe. By W. DOUGLAS HAMILTON, of University College, London, and EDWARD LEVIEN, M.A., of Balliol College, Oxford. 2s. 6d.; cloth boards, 3s. 6d.

7. **Rome, Outlines of the History of:** from the Earliest Period to the Christian Era and the Commencement of the Decline of the Empire. By EDWARD LEVIEN, of Balliol College, Oxford. Map, 2s. 6d.; cl. bds. 3s. 6d.

9. **Chronology of History, Art, Literature, and Progress,** from the Creation of the World to the Present Time. The Continuation by W. D. HAMILTON, F.S.A. 3s.; cloth boards, 3s. 6d.

50. **Dates and Events in English History,** for the use of Candidates in Public and Private Examinations. By the Rev. E. RAND. 1s.

ENGLISH LANGUAGE AND MISCELLANEOUS.

11. **Grammar of the English Tongue,** Spoken and Written. With an Introduction to the Study of Comparative Philology. By HYDE CLARKE, D.C.L. Fourth Edition. 1s. 6d.

12. **Dictionary of the English Language,** as Spoken and Written. Containing above 100,000 Words. By HYDE CLARKE, D.C.L. 3s. 6d.; cloth boards, 4s. 6d.; complete with the GRAMMAR, cloth bds., 5s. 6d.

48. **Composition and Punctuation,** familiarly Explained for those who have neglected the Study of Grammar. By JUSTIN BRENAN. 18th Edition. 1s. 6d.

49. **Derivative Spelling-Book:** Giving the Origin of Every Word from the Greek, Latin, Saxon, German, Teutonic, Dutch, French, Spanish, and other Languages; with their present Acceptation and Pronunciation. By J. ROWBOTHAM, F.R.A.S. Improved Edition. 1s. 6d.

51. **The Art of Extempore Speaking:** Hints for the Pulpit, the Senate, and the Bar. By M. BAUTAIN, Vicar-General and Professor at the Sorbonne. Translated from the French. 8th Edition, carefully corrected. 2s. 6d.

53. **Places and Facts in Political and Physical Geography,** for Candidates in Examinations. By the Rev. EDGAR RAND, B.A. 1s.

54. **Analytical Chemistry,** Qualitative and Quantitative, a Course of. To which is prefixed, a Brief Treatise upon Modern Chemical Nomenclature and Notation. By WM. W. PINK and GEORGE E. WEBSTER. 2s.

THE SCHOOL MANAGERS' SERIES OF READING BOOKS,

Edited by the Rev. A. R. GRANT, Rector of Hitcham, and Honorary Canon of Ely; formerly H.M. Inspector of Schools.

INTRODUCTORY PRIMER, 3*d*.

	s.	*d.*		*s.*	*d.*
FIRST STANDARD	0	6	FOURTH STANDARD	1	2
SECOND „	0	10	FIFTH „	1	6
THIRD „	1	0	SIXTH „	1	6

LESSONS FROM THE BIBLE. Part I. Old Testament. 1s.

LESSONS FROM THE BIBLE. Part II. New Testament, to which is added THE GEOGRAPHY OF THE BIBLE, for very young Children. By Rev. C. THORNTON FORSTER. 1s. 2d. ⁂ Or the Two Parts in One Volume. 2s.

FRENCH.

24. **French Grammar.** With Complete and Concise Rules on the Genders of French Nouns. By G. L. STRAUSS, Ph.D. 1s. 6d.

25. **French-English Dictionary.** Comprising a large number of New Terms used in Engineering, Mining, &c. By ALFRED ELWES. 1s. 6d.

26. **English-French Dictionary.** By ALFRED ELWES. 2s.

25,26. **French Dictionary** (as above). Complete, in One Vol., 3s.; cloth boards, 3s. 6d. *** Or with the GRAMMAR, cloth boards, 4s. 6d.

47. **French and English Phrase Book:** containing Introductory Lessons, with Translations, several Vocabularies of Words, a Collection of suitable Phrases, and Easy Familiar Dialogues. 1s. 6d.

GERMAN.

39. **German Grammar.** Adapted for English Students, from Heyse's Theoretical and Practical Grammar, by Dr. G. L. STRAUSS. 1s. 6d.

40. **German Reader:** A Series of Extracts, carefully culled from the most approved Authors of Germany; with Notes, Philological and Explanatory. By G. L. STRAUSS, Ph.D. 1s.

41-43. **German Triglot Dictionary.** By N. E. S. A. HAMILTON. In Three Parts. Part I. German-French-English. Part II. English-German-French. Part III. French-German-English. 3s., or cloth boards, 4s.

41-43 & 39. **German Triglot Dictionary** (as above), together with German Grammar (No. 39), in One Volume, cloth boards, 5s.

ITALIAN.

27. **Italian Grammar,** arranged in Twenty Lessons, with a Course of Exercises. By ALFRED ELWES. 1s. 6d.

28. **Italian Triglot Dictionary,** wherein the Genders of all the Italian and French Nouns are carefully noted down. By ALFRED ELWES. Vol. 1. Italian-English-French. 2s. 6d.

30. **Italian Triglot Dictionary.** By A. ELWES. Vol. 2. English-French-Italian. 2s. 6d.

32. **Italian Triglot Dictionary.** By ALFRED ELWES. Vol. 3. French-Italian-English. 2s. 6d.

28,30, 32. **Italian Triglot Dictionary** (as above). In One Vol., 7s. 6d. Cloth boards.

SPANISH AND PORTUGUESE.

34. **Spanish Grammar,** in a Simple and Practical Form. With a Course of Exercises. By ALFRED ELWES. 1s. 6d.

35. **Spanish-English and English-Spanish Dictionary.** Including a large number of Technical Terms used in Mining, Engineering, &c. with the proper Accents and the Gender of every Noun. By ALFRED ELWES 4s.; cloth boards, 5s. *** Or with the GRAMMAR, cloth boards, 6s.

55. **Portuguese Grammar,** in a Simple and Practical Form. With a Course of Exercises. By ALFRED ELWES. 1s. 6d.

56. **Portuguese-English and English-Portuguese Dictionary.** Including a large number of Technical Terms used in Mining, Engineering, &c., with the proper Accents and the Gender of every Noun. By ALFRED ELWES. Second Edition, Revised, 5s.; cloth boards, 6s. *** Or with the GRAMMAR, cloth boards, 7s.

HEBREW.

46*. **Hebrew Grammar.** By Dr. BRESSLAU. 1s. 6d.

44. **Hebrew and English Dictionary,** Biblical and Rabbinical; containing the Hebrew and Chaldee Roots of the Old Testament Post-Rabbinical Writings. By Dr. BRESSLAU. 6s.

46. **English and Hebrew Dictionary.** By Dr. BRESSLAU. 3s.

44,46. 46*. **Hebrew Dictionary** (as above), in Two Vols., complete, with the GRAMMAR, cloth boards, 12s.

LATIN.

19. **Latin Grammar.** Containing the Inflections and Elementary Principles of Translation and Construction. By the Rev. THOMAS GOODWIN, M.A., Head Master of the Greenwich Proprietary School. 1s. 6d.

20. **Latin-English Dictionary.** By the Rev. THOMAS GOODWIN, M.A. 2s.

22. **English-Latin Dictionary;** together with an Appendix of French and Italian Words which have their origin from the Latin. By the Rev. THOMAS GOODWIN, M.A. 1s. 6d.

20,22. **Latin Dictionary** (as above). Complete in One Vol., 3s. 6d. cloth boards, 4s. 6d. ⁂ Or with the GRAMMAR, cloth boards, 5s. 6d.

LATIN CLASSICS. With Explanatory Notes in English.

1. **Latin Delectus.** Containing Extracts from Classical Authors, with Genealogical Vocabularies and Explanatory Notes, by H. YOUNG. 1s. 6d.

2. **Cæsaris** Commentarii de Bello Gallico. Notes, and a Geographical Register for the Use of Schools, by H. YOUNG. 2s.

3. **Cornelius Nepos.** With Notes. By H. YOUNG. 1s.

4. **Virgilii** Maronis Bucolica et Georgica. With Notes on the Bucolics by W. RUSHTON, M.A., and on the Georgics by H. YOUNG. 1s. 6d.

5. **Virgilii** Maronis Æneis. With Notes, Critical and Explanatory, by H. YOUNG. New Edition, revised and improved With copious Additional Notes by Rev. T. H. L. LEARY, D.C.L., formerly Scholar of Brasenose College, Oxford. 3s.

5* ——— Part 1. Books i.—vi., 1s. 6d.

5** ——— Part 2. Books vii.—xii., 2s.

6. **Horace;** Odes, Epode, and Carmen Sæculare. Notes by H. YOUNG. 1s. 6d.

7. **Horace;** Satires, Epistles, and Ars Poetica. Notes by W. BROWNRIGG SMITH, M.A., F.R.G.S. 1s. 6d.

8. **Sallustii** Crispi Catalina et Bellum Jugurthinum. Notes, Critical and Explanatory, by W. M. DONNE, B.A., Trin. Coll., Cam. 1s. 6d.

9. **Terentii** Andria et Heautontimorumenos. With Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 1s. 6d.

10. **Terentii** Adelphi, Hecyra, Phormio. Edited, with Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 2s.

11. **Terentii** Eunuchus, Comœdia. Notes, by Rev. J. DAVIES, M.A. 1s. 6d.

12. **Ciceronis** Oratio pro Sexto Roscio Amerino. Edited, with an Introduction, Analysis, and Notes, Explanatory and Critical, by the Rev JAMES DAVIES, M.A. 1s. 6d.

13. **Ciceronis** Orationes in Catilinam, Verrem, et pro Archia. With Introduction, Analysis, and Notes, Explanatory and Critical, by Rev. T. H. L. LEARY, D.C.L. formerly Scholar of Brasenose College, Oxford. 1s. 6d.

14. **Ciceronis** Cato Major, Lælius, Brutus, sive de Senectute, de Amicitia, de Claris Oratoribus Dialogi. With Notes by W. BROWNRIGG SMITH M.A., F.R.G.S. 2s.

16. **Livy:** History of Rome. Notes by H. YOUNG and W. B. SMITH, M.A. Part 1. Books i., ii., 1s. 6d.

16*. ——— Part 2. Books iii., iv., v., 1s. 6d.

17. ——— Part 3. Books xxi., xxii., 1s. 6d.

19. **Latin Verse Selections,** from Catullus, Tibullus, Propertius, and Ovid. Notes by W. B. DONNE, M.A., Trinity College, Cambridge. 2s.

20. **Latin Prose Selections,** from Varro, Columella, Vitruvius, Seneca, Quintilian, Florus, Velleius Paterculus, Valerius Maximus Suetonius, Apuleius, &c. Notes by W. B. DONNE, M.A. 2s.

21. **Juvenalis Satiræ.** With Prolegomena and Notes by T. H. S. ESCOTT, B.A., Lecturer on Logic at King's College, London. 2s.

GREEK.

14. **Greek Grammar,** in accordance with the Principles and Philological Researches of the most eminent Scholars of our own day. By HANS CLAUDE HAMILTON. 1s. 6d.

15,17. **Greek Lexicon.** Containing all the Words in General Use, with their Significations, Inflections, and Doubtful Quantities. By HENRY R. HAMILTON. Vol. 1. Greek-English, 2s. 6d.; Vol. 2. English-Greek, 2s. Or the Two Vols. in One, 4s. 6d.: cloth boards, 5s.

14,15, 17. **Greek Lexicon** (as above). Complete, with the GRAMMAR, in One Vol., cloth boards, 6s.

GREEK CLASSICS. With Explanatory Notes in English.

1. **Greek Delectus.** Containing Extracts from Classical Authors, with Genealogical Vocabularies and Explanatory Notes, by H. YOUNG. New Edition, with an improved and enlarged Supplementary Vocabulary, by JOHN HUTCHISON, M.A., of the High School, Glasgow. 1s. 6d.

2, 3. **Xenophon's Anabasis;** or, The Retreat of the Ten Thousand. Notes and a Geographical Register, by H. YOUNG. Part 1. Books i. to iii., 1s. Part 2. Books iv. to vii., 1s.

4. **Lucian's Select Dialogues.** The Text carefully revised, with Grammatical and Explanatory Notes, by H. YOUNG. 1s. 6d.

5-12. **Homer,** The Works of. According to the Text of BAEUMLEIN. With Notes, Critical and Explanatory, drawn from the best and latest Authorities, with Preliminary Observations and Appendices, by T. H. L. LEARY, M.A., D.C.L.

THE ILIAD:	Part 1. Books i. to vi., 1s. 6d.	Part 3. Books xiii. to xviii., 1s. 6d.
	Part 2. Books vii. to xii., 1s. 6d.	Part 4. Books xix. to xxiv., 1s. 6d.
THE ODYSSEY:	Part 1. Books i. to vi., 1s. 6d	Part 3. Books xiii. to xviii., 1s. 6d.
	Part 2. Books vii. to xii., 1s. 6d.	Part 4. Books xix. to xxiv., and Hymns, 2s.

13. **Plato's Dialogues:** The Apology of Socrates, the Crito, and the Phædo. From the Text of C. F. HERMANN. Edited with Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 2s.

14-17. **Herodotus,** The History of, chiefly after the Text of GAISFORD. With Preliminary Observations and Appendices, and Notes, Critical and Explanatory, by T. H. L. LEARY, M.A., D.C.L.
Part 1. Books i., ii. (The Clio and Euterpe), 2s.
Part 2. Books iii., iv. (The Thalia and Melpomene), 2s.
Part 3. Books v.-vii. (The Terpsichore, Erato, and Polymnia), 2s.
Part 4. Books viii., ix. (The Urania and Calliope) and Index, 1s. 6d.

18. **Sophocles:** Œdipus Tyrannus. Notes by H. YOUNG. 1s.

20. **Sophocles:** Antigone. From the Text of DINDORF. Notes, Critical and Explanatory, by the Rev. JOHN MILNER, B.A. 2s.

23. **Euripides:** Hecuba and Medea. Chiefly from the Text of DINDORF. With Notes, Critical and Explanatory, by W. BROWNRIGG SMITH, M.A., F.R.G.S. 1s. 6d.

26. **Euripides:** Alcestis. Chiefly from the Text of DINDORF. With Notes, Critical and Explanatory, by JOHN MILNER, B.A. 1s. 6d.

30. **Æschylus:** Prometheus Vinctus: The Prometheus Bound. From the Text of DINDORF. Edited, with English Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 1s.

32. **Æschylus:** Septem Contra Thebes: The Seven against Thebes. From the Text of DINDORF. Edited, with English Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 1s.

40. **Aristophanes:** Acharnians. Chiefly from the Text of C. H. WEISE. With Notes, by C. S. T. TOWNSHEND, M.A. 1s. 6d.

41. **Thucydides:** History of the Peloponnesian War. Notes by H. YOUNG. Book 1. 1s. 6d.

42. **Xenophon's Panegyric on Agesilaus.** Notes and Introduction by LL. F. W. JEWITT. 1s. 6d.

43. **Demosthenes.** The Oration on the Crown and the Philippics. With English Notes. By Rev. T. H. L. LEARY, D.C.L., formerly Scholar of Brasenose College, Oxford. 1s. 6d.